Equivalent Transformations for the Mixed Lumped Richards Section and Distributed Transmission Line

YOSHIAKI NEMOTO, MEMBER, IEEE, MAKOTO SATAKE,
KUNIKATSU KOBAYASHI, MEMBER, IEEE, AND RISABURO SATO, FELLOW, IEEE

Abstract —**Introducing a new analysis method for the nonuniform transmission line, this paper shows equivalent transformations between a circuit consisting of a cascade connection of a lumped Richards section, an ideal transformer, and a distributed transmission line and one consisting of a cascade connection of a class of a nonuniform transmission line, a lumped Richards section, and an ideal transformer. Characteristic impedance distributions of these nonuniform transmission lines are expressed as hyperbolic or trigonometric functions. It is quite difficult to find the exact network functions of nonuniform transmission lines from the telegraph equation, but by using the equivalent transformation described it becomes possible to obtain exact network functions of a class of nonuniform transmission lines.**

I. Introduction

PREVIOUSLY a powerful analysis method for nonuniform transmission lines was used to derive equivalent transformations for mixed lumped and distributed circuits [5]–[8]. This paper shows a new type of equivalent transformation. First we show an equivalent transformation for a circuit consisting of a cascade connection of a distributed Richards section, an ideal transformer, and a uniform transmission line (unit element). By applying this equivalent transformation n times and considering the limiting case of $n \to \infty$, the transformed circuit consists of a cascade connection of a nonuniform transmission line, a lumped Richards section, and an ideal transformer. The characteristic impedance distribution of this nonuniform transmission line is expressed as a hyperbolic function of distance x. Then, we apply this technique to a circuit containing an imaginary instead of a real gyrator, and obtain the equivalent circuit of another type of nonuniform transmission line whose characteristic impedance distribution is expressed as a trigonometric function of distance x. Next, we treat the equivalent transformation of a circuit consisting of a lumped Richards section and a nonuniform transmission line. Characteristic impedance distributions of the newly obtained nonuniform transmission lines are expressed as a function of the characteristic impedance distribution and the elements of the chain matrix (A, B, C, D) of the original nonuniform transmission line. By using these equivalent transformations, exact network functions of a class of nonuniform transmission lines can be obtained without solving the telegraph equation.

Manuscript received May 27, 1987; revised October 27, 1987.
Y. Nemoto is with the Research Institute of Electrical Communication, Tohoku University, Sendai 980, Japan.
M. Satake is with the Department of Information Science, Faculty of Engineering, Tohoku University, Sendai 980, Japan.
K. Kobayashi is with the Department of Electrical Engineering, Faculty of Engineering, Yamagata University, Yonezawa 992, Japan.
R. Sato is with the Department of Electrical Engineering, Faculty of Engineering, Tohoku Gakuin University, Tagajo 985, Japan.
IEEE Log Number 8719209.

II. Equivalent Transformation for a Lumped Richards Section and a Uniform Transmission Line

The Richards section is one of the important circuits for cascade network synthesis [9]. In the case of distributed circuits, the distributed Richards section is constructed of a gyrator and a single shorted stub, and its chain matrix is given as follows:

$$[F] = \frac{1}{1+\dfrac{p}{\sigma}} \begin{bmatrix} \dfrac{p}{\sigma} & R_0 \\ \dfrac{1}{R_0} & \dfrac{p}{\sigma} \end{bmatrix} \tag{1}$$

where R_0 is the gyration ratio of the gyrator, R_0/σ is the characteristic impedance of the single shorted stub, and p is the Richards variable.

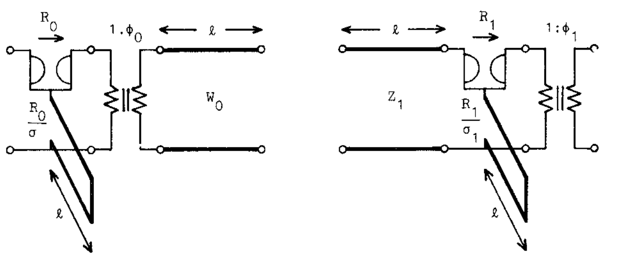
We consider a circuit consisting of a cascade connection of a distributed Richards section, an ideal transformer, and a unit element, shown in Fig. 1(a), where W_0 is the characteristic impedance of the unit element and ϕ_0 is the turns ratio of the ideal transformer. The distributed Richards section can be transformed to the output port as shown in Fig. 1(b). The formulas for this transformation are given as follows:

$$Z_1 = \frac{R_0(W_0 + \sigma\phi_0^2 R_0)}{\sigma W_0 + \phi_0^2 R_0} \tag{2}$$

$$\phi_1 = \frac{W_0(\sigma W_0 + \phi_0^2 R_0)}{\phi_0 R_0(W_0 + \sigma\phi_0^2 R_0)} \tag{3}$$

$$R_1 = \frac{\phi_0^2 R_0^2(W_0 + \sigma\phi_0^2 R_0)}{W_0(\sigma W_0 + \phi_0^2 R_0)} \tag{4}$$

$$\sigma_1 = \sigma. \tag{5}$$



(a) (b)

Fig. 1. Equivalent transformation for distributed Richards section. (a) Original. (b) Equivalent.

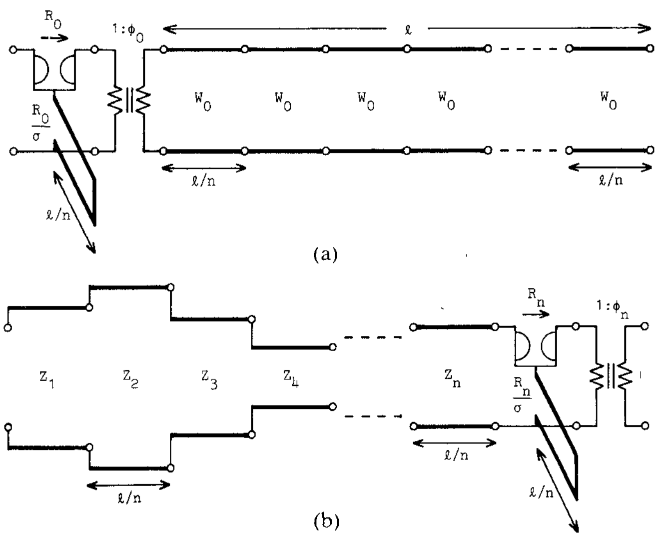


Fig. 2. N-times equivalent transformations. (a) Original. (b) Equivalent.

This transformation can be applied n times (n an integer) to the circuit shown in Fig. 2(a), where the line lengths of the unit elements and the single shorted stub are l/n. The transformed circuit is one consisting of a cascade connection of cascaded transmission lines, the distributed Richards section, and an ideal transformer as shown in Fig. 2(b).

The characteristic impedance Z_i of a unit element and the element values of the circuit transformed the ith time are given as follows:

$$Z_i = \frac{W_0}{\phi_{i-1}\phi_i} \qquad (i=1,2,\cdots,n) \tag{6}$$

$$\phi_i = \frac{W_0}{\phi_0 R_0} \cdot \frac{\dfrac{(1+\sigma)^i+(1-\sigma)^i}{2}\phi_0^2 R_0 + \dfrac{(1+\sigma)^i-(1-\sigma)^i}{2} W_0}{\dfrac{(1+\sigma)^i+(1-\sigma)^i}{2} W_0 + \dfrac{(1+\sigma)^i-(1-\sigma)^i}{2}\phi_0^2 R_0} \tag{7}$$

$$R_n = \frac{\phi_0 R_0}{\phi_n}. \tag{8}$$

By considering the limiting case of the above transformation ($n \to \infty$), we can discuss the equivalent transformation for the mixed lumped and distributed circuit [5]–[8]. Set

$$\sigma = \frac{\sigma_0}{n}. \tag{9}$$

By proceeding to the limit $n \to \infty$, the driving point impedance of the single shorted stub shown in Fig. 2(a) yields

$$Z_{\text{in}} = \lim_{n\to\infty}\left(j\frac{R_0}{\sigma}\tan\frac{\beta l}{n}\right) = j\frac{R_0}{\sigma_0}\beta l = j\frac{R_0}{\sigma_0}\frac{l}{v}\omega \tag{10}$$

where β is the phase constant, ω is the angular frequency, and v is the velocity of light; i.e., the single shorted stub becomes a lumped inductor. The coordinate x of the ith unit element of the transformed circuit is given as follows:

$$x = \frac{i}{n} l \qquad (i=1,2,\cdots,n). \tag{11}$$

By substituting (9) and (11) into (6) and (7), we obtain the following relations as $n \to \infty$:

$$\lim_{n\to\infty}\phi_i = \frac{W_0}{\phi_0 R_0}\cdot\frac{\phi_0^2 R_0\cosh\dfrac{\sigma_0 x}{l} + W_0\sinh\dfrac{\sigma_0 x}{l}}{W_0\cosh\dfrac{\sigma_0 x}{l} + \phi_0^2 R_0\sinh\dfrac{\sigma_0 x}{l}} \equiv \phi(x) \tag{12}$$

$$\lim_{n\to\infty} Z_i = \frac{W_0}{\phi(x)^2} = \frac{(\phi_0 R_0)^2}{W_0}\cdot\left(\frac{W_0\cosh\dfrac{\sigma_0 x}{l} + \phi_0^2 R_0\sinh\dfrac{\sigma_0 x}{l}}{\phi_0^2 R_0\cosh\dfrac{\sigma_0 x}{l} + W_0\sinh\dfrac{\sigma_0 x}{l}}\right)^2 \equiv Z(x). \tag{13}$$

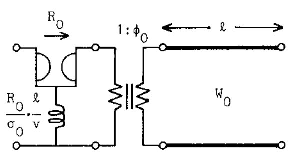
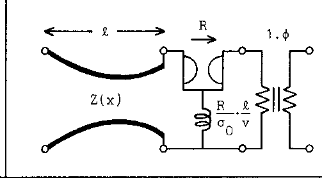
$Z(x)$ is the characteristic impedance distribution of the nonuniform transmission line derived. That is, if the transformation shown in Fig. 1 is applied n times as $n \to \infty$, the characteristic impedance distribution of the transformed circuit transforms from a discrete function of distance x into a continuous function. Under these conditions the element values of the Richards section of the transformed circuit become

$$\phi = \phi(x)|_{x=l} \tag{14}$$

$$R = \frac{\phi_0 R_0}{\phi}. \tag{15}$$

In the limiting case we obtain the equivalent transformation shown in Table I. By using this we can show the

TABLE I
EQUIVALENT TRANSFORMATION FOR THE CIRCUIT CONSISTING OF LUMPED RICHARDS SECTION, IDEAL TRANSFORMER, AND UNIFORM TRANSMISSION LINE

Original Circuit	Equivalent Circuit
	

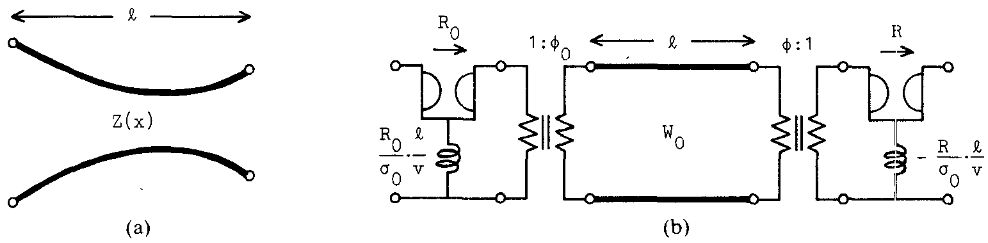


Fig. 3. Equivalent circuit of nonuniform transmission line $Z(x)$ in (13). (a) Nonuniform transmission line. (b) Equivalent circuit.

equivalent circuit of a nonuniform transmission line $Z(x)$ in (13) as shown in Fig. 3. Network functions of this nonuniform transmission line can be easily obtained from the equivalent circuit. The chain matrix is given as follows:

$$[F]=\begin{bmatrix} A & B \\ C & D \end{bmatrix}=\frac{1}{s^2-\left(\sigma_0\frac{v}{l}\right)^2}\begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} \tag{16}$$

$$A'=s^2\frac{\phi}{\phi_0}\cos\beta l+js\frac{\sigma_0 v}{l}\left(\frac{\phi^2 R}{W_0}-\frac{W_0}{\phi_0^2 R_0}\right)\sin\beta l-\left(\frac{\sigma_0 v}{l}\right)^2\cos\beta l \tag{17}$$

$$B'=js^2\frac{W_0}{\phi_0\phi}\sin\beta l+s\frac{\sigma_0 v}{l}(R-R_0)\cos\beta l-j\left(\frac{\sigma_0 v}{l}\right)^2\frac{\phi_0^2 R_0^2}{W_0}\sin\beta l \tag{18}$$

$$C'=js^2\frac{\phi_0\phi}{W_0}\sin\beta l+s\frac{\sigma_0 v}{l}\left(\frac{1}{R}-\frac{1}{R_0}\right)\cos\beta l-j\left(\frac{\sigma_0 v}{l}\right)^2\frac{W_0}{\phi_0^2 R_0^2}\sin\beta l \tag{19}$$

$$D'=s^2\frac{\phi_0}{\phi}\cos\beta l+js\frac{\sigma_0 v}{l}\left(\frac{W_0}{\phi^2 R}-\frac{\phi_0^2 R_0}{W_0}\right)\sin\beta l-\left(\frac{\sigma_0 v}{l}\right)^2\cos\beta l \tag{20}$$

where s is the complex angular frequency.

The above transformation technique may also be applied to a circuit that has the same topology as that of Fig. 2 but with the real gyrator R_0 and σ changed to an imaginary gyrator jR_0 and $j\omega$, respectively. In a circuit containing an imaginary gyrator, a Richards section and an ideal transformer can be transformed to the output port by changing the characteristic impedances of the unit elements. The element values of the transformed circuit are given as follows:

$$Z_i=\frac{W_0}{\phi_{i-1}\phi_i} \qquad (i=1,2,\cdots,n) \tag{21}$$

$$\phi_i=\frac{W_0}{j\phi_0 R_0}\cdot\frac{\frac{(1+j\omega)^i+(1-j\omega)^i}{2}j\phi_0^2 R_0+\frac{(1+j\omega)^i-(1-j\omega)^i}{2}W_0}{\frac{(1+j\omega)^i+(1-j\omega)^i}{2}W_0+\frac{(1+j\omega)^i-(1-j\omega)^i}{2}j\phi_0^2 R_0} \tag{22}$$

$$jR_n=\frac{j\phi_0 R_0}{\phi_n}. \tag{23}$$

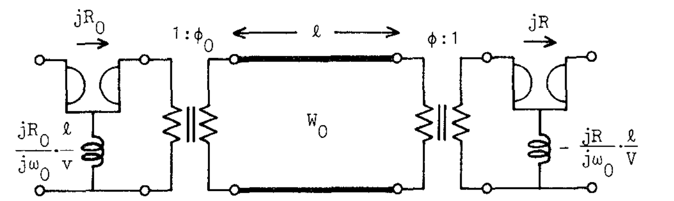


Fig. 4. Equivalent circuit of nonuniform transmission line $Z(x)$ in (26).

Here, we set

$$j\omega = \frac{j\omega_0}{n}. \tag{24}$$

By substituting (11) and (24) into (21) and (22) and proceeding to the limit $n \to \infty$, we obtain

$$\phi(x) = \lim_{n\to\infty} \phi_i = \frac{W_0}{\phi_0 R_0} \frac{\phi_0^2 R_0 \cos\frac{\omega_0 x}{l} + W_0 \sin\frac{\omega_0 x}{l}}{W_0 \cos\frac{\omega_0 x}{l} - \phi_0^2 R_0 \sin\frac{\omega_0 x}{l}} \tag{25}$$

$$Z(x) = \lim_{n\to\infty} Z_i = \frac{W_0}{\phi(x)^2} = \frac{(\phi_0 R_0)^2}{W_0} \left(\frac{W_0 \cos\frac{\omega_0 x}{l} - \phi_0^2 R_0 \sin\frac{\omega_0 x}{l}}{\phi_0^2 R_0 \cos\frac{\omega_0 x}{l} + W_0 \sin\frac{\omega_0 x}{l}} \right)^2. \tag{26}$$

The cascaded transmission lines become nonuniform transmission lines with characteristic impedance distribution $Z(x)$.

Under these conditions, the single shorted stubs become lumped inductors and the element values of the transformed circuit are given by

$$\phi = \phi(x)|_{x=l} \tag{27}$$

$$R = \frac{\phi_0 R_0}{\phi}. \tag{28}$$

Finally we obtain the equivalent circuit of the nonuniform transmission line $Z(x)$ in (26) as shown in Fig. 4.

III. Equivalent Transformation for a Lumped Richards Section and a Nonuniform Transmission Line

The circuit consisting of a distributed Richards section, an ideal transformer, and cascaded transmission lines is shown in Fig. 5(a). Here we denote the chain matrix of the cascaded transmission lines as follows:

$$[F] = \prod_{i=1}^{n} \left(\frac{1}{\sqrt{1-p^2}} \begin{bmatrix} 1 & W_i p \\ \frac{1}{W_i} p & 1 \end{bmatrix} \right) = \begin{bmatrix} A_n(p) & B_n(p) \\ C_n(p) & D_n(p) \end{bmatrix} \tag{29}$$

where p is the Richards variable.

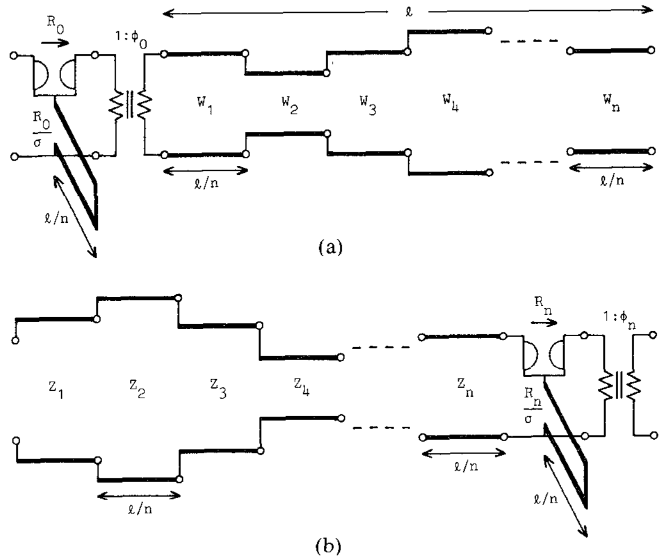


Fig. 5. N-times equivalent transformations. (a) Original. (b) Equivalent.

By applying the equivalent transformation shown in Fig. 1 to this circuit, we obtain the equivalent circuit shown in Fig. 5(b). Element values of the circuit transformed i times, shown in Fig. 5(b), are given by

$$\phi_i = \frac{1}{\phi_0 R_0} \cdot \frac{\phi_0^2 R_0 D_i(p) + B_i(p)}{A_i(p) + \phi_0^2 R_0 C_i(p)} \bigg|_{p=\sigma} \qquad (i = 1, 2, \cdots, n) \tag{30}$$

$$Z_i = \frac{W_i}{\phi_{i-1}\phi_i} \qquad (i = 1, 2, \cdots, n) \tag{31}$$

$$R_n = \frac{\phi_0 R_0}{\phi_n}. \tag{32}$$

Here the turns ratio ϕ_i of an ideal transformer is expressed as a function of elements of the chain matrix, with p in (29) replaced by σ.

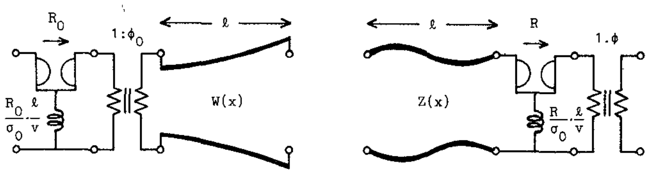
Then by using (9) and (11) and proceeding to the limit $n \to \infty$, the distributed Richards sections and cascaded transmission lines of Fig. 5 become equal to the lumped Richards sections and nonuniform transmission lines shown in Fig. 6. The characteristic impedance distribution $Z(x)$ and the element values ϕ and R of the transformed circuit shown in Fig. 6(b) are obtained as follows:

$$Z(x) = \frac{W(x)}{\phi(x)^2} \tag{33}$$

$$\phi(x) = \frac{1}{\phi_0 R_0} \cdot \frac{\phi_0^2 R_0 D\left(\sigma_0 \frac{x}{l}\right) + B\left(\sigma_0 \frac{x}{l}\right)}{A\left(\sigma_0 \frac{x}{l}\right) + \phi_0^2 R_0 C\left(\sigma_0 \frac{x}{l}\right)} \tag{34}$$

$$\phi = \phi(x)|_{x=l} \qquad R = \phi_0 R_0 / \phi \tag{35}$$

where $A(\sigma_0 x/l)$, $B(\sigma_0 x/l)$, $C(\sigma_0 x/l)$, and $D(\sigma_0 x/l)$ are elements of the chain matrix of the original nonuniform transmission line.



(a) (b)

Fig. 6. Equivalent transformation for a circuit consisting of a lumped Richards section, an ideal transformer, and a nonuniform transmission line. (a) Original. (b) Equivalent.

Example 1: This is a circuit consisting of a cascade connection of a lumped Richards section, an ideal transformer, and a parabolic tapered transmission line. The characteristic impedance distribution $W(x)$ and the elements of the chain matrix of the parabolic tapered transmission line are given as follows [6]:

$$W(x)=W_0 m(x)^2 \tag{36}$$

$$A\left(\frac{\sigma_0 x}{l}\right)=\frac{1}{m(x)}\left(\cosh\frac{\sigma_0 x}{l}+\frac{1}{h\sigma_0}\sinh\frac{\sigma_0 x}{l}\right) \tag{37}$$

$$B\left(\frac{\sigma_0 x}{l}\right)=W_0\left\{m(x)\left(\sinh\frac{\sigma_0 x}{l}+\frac{1}{h\sigma_0}\cosh\frac{\sigma_0 x}{l}\right)-\frac{1}{h\sigma_0}\left(\cosh\frac{\sigma_0 x}{l}+\frac{1}{h\sigma_0}\sinh\frac{\sigma_0 x}{l}\right)\right\} \tag{38}$$

$$C\left(\frac{\sigma_0 x}{l}\right)=\frac{1}{W_0 m(x)}\sinh\frac{\sigma_0 x}{l} \tag{39}$$

$$D\left(\frac{\sigma_0 x}{l}\right)=m(x)\cosh\frac{\sigma_0 x}{l}-\frac{1}{h\sigma_0}\sinh\frac{\sigma_0 x}{l} \tag{40}$$

where h is the taper coefficient of the parabolic tapered transmission line. The characteristic impedance distribution $Z(x)$ of the newly obtained nonuniform transmission line is given as

$$Z(x)=W_0\left[\frac{\cosh\dfrac{\sigma_0 x}{l}+\left(\dfrac{1}{h\sigma_0}+\dfrac{\phi_0^2 R_0}{W_0}\right)\sinh\dfrac{\sigma_0 x}{l}}{\left(\phi_0 m(x)+\dfrac{W_0}{\phi_0 R_0 h^2\sigma_0}\cdot\dfrac{x}{l}\right)\cosh\dfrac{\sigma_0 x}{l}+\left(\dfrac{W_0}{\phi_0 R_0}m(x)-\dfrac{\phi_0}{h\sigma_0}-\dfrac{W_0}{\phi_0 R_0 (h\sigma_0)^2}\right)\sinh\dfrac{\sigma_0 x}{l}}\right]^2 \tag{41}$$

$$m(x)=1+\frac{1}{h}\cdot\frac{x}{l}. \tag{42}$$

The above transformation technique may be applied to a circuit consisting of a lumped imaginary Richards section, an ideal transformer, and a nonuniform transmission line. In this case, by using relations (11) and (24) and proceeding to the limit of $n\to\infty$, the element values of the transformed circuit are obtained as follows:

$$Z(x)=\frac{W(x)}{\phi(x)^2} \tag{43}$$

$$\phi(x)=\frac{1}{j\phi_0 R_0}\cdot\frac{j\phi_0^2 R_0 D(\omega_0 x/l)+B(\omega_0 x/l)}{A(\omega_0 x/l)+j\phi_0^2 R_0 C(\omega_0 x/l)} \tag{44}$$

where $W(x)$ is the characteristic impedance distribution and $A(\omega_0 x/l)$, $B(\omega_0 x/l)$, $C(\omega_0 x/l)$, and $D(\omega_0 x/l)$ are elements of the chain matrix of the original nonuniform transmission line with the propagation constant σ_0 of (34) changed to $j\omega_0$. So the equivalent circuit of the nonuniform transmission line $Z(x)$ in (43) can be obtained as shown in Fig. 7.

Example 2: This is a circuit consisting of a lumped imaginary Richards section, an ideal transformer, and a parabolic tapered transmission line. In this case, the characteristic impedance distribution $Z(x)$ of the nonuniform transmission line obtained after transformation is given as follows:

$$Z(x)=W_0\left[\frac{\cos\dfrac{\omega_0 x}{l}+\left(\dfrac{1}{h\omega_0}-\dfrac{\phi_0 R_0}{W_0}\right)\sin\dfrac{\omega_0 x}{l}}{\left\{\phi_0 m(x)-\dfrac{W_0}{\phi_0 R_0 h^2\omega_0}\cdot\dfrac{x}{l}\right\}\cos\dfrac{\omega_0 x}{l}+\left\{\dfrac{W_0}{\phi_0 R_0}m(x)-\dfrac{\phi_0}{h\omega_0}+\dfrac{W_0}{\phi_0 R_0 (h\omega_0)^2}\right\}\sin\dfrac{\omega_0 x}{l}}\right]^2 \tag{45}$$

$$m(x)=1+\frac{1}{h}\cdot\frac{x}{l}. \tag{46}$$

Using this transformation the above operation may be carried out repeatedly. Exact network functions for a class of nonuniform transmission lines, of which the characteristic impedance distribution is represented by a hyperbolic function or a trigonometric function, are derived successively. In the case of these characteristic impedance distributions, it is very difficult to obtain the solution from the telegraph equation. However, using this method, exact solutions can be simply determined, and the new technique is useful for analyzing nonuniform transmission lines. It is pointed out that whenever the number of equivalent trans-

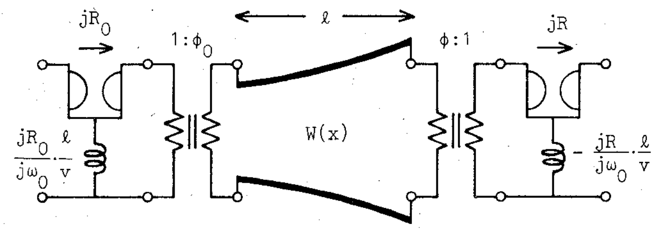


Fig. 7. Equivalent circuit of nonuniform transmission line $Z(x)$ in (43).

formations is increased, the number of free parameters increases.

IV. Conclusions

Using a new analysis method for nonuniform transmission lines, we have shown equivalent transformations for mixed lumped and distributed circuits. First, we showed an equivalent transformation for a circuit consisting of a cascade connection of a distributed Richards section, an ideal transformer, and a unit element. This was followed by an equivalent transformation for a mixed lumped Richards section, an ideal transformer, and a unit element. The transformation was then applied to a circuit containing an imaginary gyrator, and another type of nonuniform transmission line was obtained. Finally a similar transformation was applied to a circuit consisting of a lumped Richards section and a nonuniform transmission line. Exact network functions of a class of nonuniform transmission lines were obtained.

Acknowledgment

The authors wish to thank the reviewers and the editor for helpful suggestions, which have improved the readability of the paper.

References

[1] C. R. Burrows, "The exponential transmission line," *Bell Syst. Tech. J.*, vol. 17, pp. 555–573, Oct. 1938.
[2] H. Kaufman, "Bibliography of nonuniform transmission lines," *IRE Trans. Antennas Propagat.*, vol. AP-3, pp. 218–220, Oct. 1955.
[3] C. P. Womack, "The use of exponential transmission lines in microwave components," *IRE Trans. Microwave Theory Tech.*, vol. MTT-10, pp. 124–132, Mar. 1962.
[4] M. J. Ahmed, "Impedance transformation equations for exponential, cosine-squared, and parabolic tapered transmission lines," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-29, pp. 67–68, Jan. 1981.
[5] K. Kobayashi, Y. Nemoto, and R. Sato, "Kuroda's identity for mixed lumped and distributed circuits and their application to nonuniform transmission lines," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-29, pp. 81–86, Feb. 1981.
[6] K. Kobayashi, Y. Nemoto, and R. Sato, "Equivalent representations of nonuniform transmission lines based on the extended Kuroda's identity," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 140–146, Feb. 1982.
[7] I. Endo, Y. Nemoto, and R. Sato, "Equivalent representations of lossy nonuniform transmission lines," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 457–462, June 1983.
[8] Y. Nemoto, M. Satake, and R. Sato, "Equivalent transformation for the mixed lumped Richards' section and distributed circuit," in *Proc. Int. Symp. Electromagn. Compat.*, Oct. 1984, pp. 634–637.
[9] D. C. Youla, "A new theory of cascade synthesis," *IRE Trans. Circuit Theory*, vol. CT-8, pp. 244–260, Sept. 1961.

Yoshiaki Nemoto (S'72–M'73) was born in Sendai City, Miyagiken, Japan, on December 2, 1945. He received the B.E., M.E., and Ph.D. degrees from Tohoku University, Sendai, Japan, in 1968, 1970, and 1973, respectively.

From 1973 to 1984, he was a Research Associate with the Faculty of Engineering, Tohoku University. Since 1984, he has been an Associate Professor with the Research Institute of Electrical Communication at the same university. He has been engaged in research work on distributed networks, satellite communication, and computer networks using satellites. He was a corecipient of the 1982 Microwave Prize from the IEEE Microwave Theory and Techniques Society.

Dr. Nemoto is a member of the Institute of Electronics, Information and Communication Engineers of Japan, and the Information Processing Society of Japan.

Makoto Satake was born in Kawaguchi, Japan, on May 28, 1961. He received the B.E. and M.E. degrees from Tohoku University, Sendai, Japan, in 1984 and 1986, respectively.

Since 1986, he has been with Kashima Space Research Center of Radio Research Laboratory, Japan. He has been engaged in research on microwave remote sensing.

Mr. Satake is a member of the Institute of Electronics, Information and Communication Engineers of Japan.

Kunikatsu Kobayashi (M'82) was born in Yamagata, Japan, on December 22, 1943. He received the B.E. and M.E. degrees from Yamagata University, Yonezawa, Japan, in 1966 and 1971, respectively.

From 1971 to 1975, he was a Research Associate with the Faculty of Engineering, Yamagata University, and in 1975 he became a Lecturer at the same university. He has been engaged in research on nonuniform transmission lines. He was corecipient of the 1982 Microwave Prize from the IEEE MTT-S.

Dr. Kobayashi is a member of the Institute of Electronics, Information and Communication Engineers of Japan.

Risaburo Sato (SM'62–F'77) was born in Furukawa City, Miyagiken, Japan, on September 23, 1921. He received the B.E. and Ph.D. degrees from Tohoku University, Sendai, Japan, in 1944 and 1952, respectively.

From 1949 to 1961, he was an Associate Professor at Tohoku University, and in 1961 he became a Professor in the Department of Electrical Communication at the same university. From 1973 to 1984, he was a Professor in the Department of Information Science at Tohoku University. He is presently an Emeritus Professor of Tohoku University and

Dean of the Faculty of Engineering of Tohoku Gakuin University, Tagajo-shi, Japan. From 1969 to 1970, he was an International Research Fellow at Stanford Research Institute, Menlo Park, CA. His research activities include studies of multiconductor transmission systems, distributed transmission circuits, antennas, communication systems, active transmission lines, magnetic and ferroelectric recording, neural information processing, computer networks, and electromagnetic compatibility. He has published a number of technical papers and books in these fields, including *Transmission Circuits*. He received a Best Paper Award from the Institute of Electrical Engineers of Japan (IEE of Japan) in 1955, the Kahoku Press Cultural Award in 1963, an award from the Invention Association of Japan in 1966, a Best Paper Award from the Institute of Electronics, Information and Communication Engineers of Japan (IEICE of Japan) in 1980, a Certificate of Appreciation of Electromagnetic Compatibility from the IEEE in 1981, the Microwave Prize of the IEEE Microwave Theory and Techniques Society in 1982, the IEEE Centennial Medal 1984, the Distinguished Service Award from the IECE of Japan in 1984, and the Laurence G. Cumming Award IEEE EMC-S, 1987.

Dr. Sato was the Vice President of IEICE of Japan from 1974 to 1976. He has been a member of the Science Council of Japan from 1978 and a member of the Telecommunication Technology Consultative Committee at NTT from 1976. He is chairman of the Tokyo chapter of the IEEE Electromagnetic Compatibility Society and a member of that Society's Board of Directors. He is also a member of the IEICE of Japan, the IEE of Japan, the Institute of Television Engineers of Japan, and the Information Processing Society of Japan.