IMPEDANCE SYNTHESIS METHOD FOR AN ELECTRICALLY SMALL ANTENNA

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1. Introduction

This paper reports on an impedance synthesis method in which an electrically small antenna is taken conjugate impedance matching. The purpose is to compensate the ohmic loss and input reactance of the small antenna, and to amplify the small signal if necessary. The negative impedance which is generated by a negative impedance converter(NIC) circuit is well known[1][2]. However, the design and manufacture of an NIC circuit at an especially high frequency is difficult in comparison to that of an amplifier. In this paper, it is proposed that the conjugate matching impedance including the negative resistance to cancel the ohmic loss and input reactance of the small antenna can be synthesized by an ordinary amplifier at a high frequency.

2. Equivalent Circuit of Small Antenna

The equivalent circuit of a small antenna is shown in Fig.1 as a receiving antenna, where, R_r, R_ℓ and X_a are the radiation resistance, the loss resistance and the input reactance of the small antenna, respectively. R_L is the load resistance. Z_t is the compensation impedance which is synthesized to cancel the ohmic loss and input reactance of the small antenna.

3. Synthesis Method for Compensation Impedance

3-1. Expression of Amplifier

Let us consider a high-frequency amplifier with three terminals, that is, input, output and common terminals, as shown in Fig.2(a). The amplifier circuit is constructed so as to be capable of adjusting the phase and gain. This is a 2-port network, and the circuit lumping together the whole of Fig.2(a) is shown in Fig.2(b).

If we denote, respectively, the elements of the S-parameter of the amplifier by S_{11}, S_{12}, S_{21}, S_{22}, and incident and reflected waves by a_1, a_2, b_1, b_2, as shown in Fig.2(b), we have the following relation.

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \tag{1}$$

Then, the incident and reflected waves corresponding to the voltages and currents at each port in Fig.2(b) can be expressed by their definitions[3] as follows, respectively.

$$2\sqrt{Z_0} \begin{pmatrix} a_1 \\ b_1 \end{pmatrix} = \begin{pmatrix} 1 & Z_0 \\ 1 & -Z_0 \end{pmatrix} \begin{pmatrix} V_1 \\ I_1 \end{pmatrix} \tag{2}$$

$$2\sqrt{Z_0} \begin{pmatrix} a_2 \\ b_2 \end{pmatrix} = \begin{pmatrix} 1 & Z_0 \\ 1 & -Z_0 \end{pmatrix} \begin{pmatrix} V_2 \\ I_2 \end{pmatrix} \tag{3}$$

From Eqs.(1),(2) and (3),the equivalent circuit of the amplifier is illustrated in Fig.2(c),where $Z_{11}, Z_{12}, Z_{21}, Z_{22}$ are given as a function of the S-parameter.

3-2.Impedance Synthesis Method

Let us consider the impedance between terminals #1 and #2 in Fig.2(a) because this choice only is possible among the three terminals #1,#2 and #3 as two-terminal impedance capable of being adjusted by the phase and gain. If we can express the above-mentioned impedance in terms of the S-parameter of the 2-port amplifier,the problem of impedance synthesis may be replaced by the design of the S-parameter of an ordinary amplifier. It is now easy through the considerable progress of the network analyzer equipment to estimate and measure the transmission characteristics between the input and the output of the 2-port amplifier. Various high-frequency transistors for amplification also have been developed,and we can use conventional high-frequency design techniques of the amplifier by means of the S-parameter. Thus,we consider the impedance synthesis method which replaces the required impedance value including the negative resistance in the real part by the S-parameter which sufficiently determines the small-signal transmission characteristics. In this case,the next relation must be held by using the two-terminal impedance,as seen from Fig.2(b).

$$I_2 = -I_1 \qquad (4)$$

From Eqs.(2),(3) and (4)

$$a_2 - b_2 = -(a_1 - b_1) \qquad (5)$$

is obtained. By solving simultaneous equations of Eqs.(2) (3) and (5),we obtain the relations among incident and reflected waves,namely,a_1, a_2, b_1, b_2 as follows.

$$b_1 = \{S_{11}(1-S_{22})-S_{12}(1-S_{21})\}/(1-S_{12}-S_{22})\ a_1 \qquad (6)$$

$$b_2 = \{S_{21}(1-S_{12})-S_{22}(1-S_{11})\}/(1-S_{12}-S_{22})\ a_1 \qquad (7)$$

$$a_2 = -(1-S_{21}-S_{11})/(1-S_{12}-S_{22})\ a_1 \qquad (8)$$

Under the condition of Eq.(4),the two-terminal impedance Z_t must be defined by the following expression.

$$Z_t = (V_1 - V_2)/(I_1) \qquad (9)$$

Since voltages and currents in Eq.(9) are represented as a function of incident and refrected waves, Eq.(9) is rewritten as follows.

$$Z_t/Z_0 = \{(a_1+b_1)-(a_2+b_2)\}/(a_1-b_1) \qquad (10)$$

where Z_0 is the characteristic impedance under the condition of the S-parameter measurement.

By substituting Eqs.(6),(7) and (8) into Eq.(10),the expression combining the impedance with the S-parameter of the amplifier is obtained as follows.

$$\frac{Z_t}{Z_0} = 2\frac{(1-S_{12})(1-S_{21})-S_{11}S_{22}}{(1-S_{11})(1-S_{22})-S_{12}S_{21}} \quad (11)$$

If the configuration of the amplifier is a three terminal type, i.e., input, output and common terminals, as illustlated in Figs.2(a) and (b), Eq.(11) holds generally, because an approximation is not used in its derivation.

Conveniently, the reverse transmission coefficient S_{12} of the transistor amplifier can be designed so as to become very small because of the unilateral amplification characteristics. The reflection coefficients S_{11} and S_{22} also are able to be made nearly zero by the impedance matching circuit. Then, we obtain a simple formula from Eq.(11) as follows.

$$Z_t = -2(S_{21}-1)Z_0 \quad (12)$$

When both conditions of the unilaterality and impedance-matching of the amplifier are satisfied, we can perform an equivalent transformation between S_{21} and Z_t. The locus of Z_t given by Eq.(12) is shown in Fig.3. The phase ϕ_{21} and gain, i.e. the amplitude $|S_{21}|$, of the transmission factor S_{21} can be controlled by the circuits(ϕ and Att.) shown in Fig.2(a). Therefore, it is obvious that the compensation impedance including the negative resistance can be synthesized by using the amplifier shown in Fig. 2(a).

4. Discussion

Since a synthesized impedance consists of an active circuit, there exists noise generated from the amplifier. It is required for noise improvement to choose transistors, analogous to the case of amplifiers.

We can transform the S-parameter at Z_0 to a different S-parameter corresponding to another characteristic impedance. Therefore, if the input and output ports of the amplifier are matched to a certain characteristic impedance, S_{11} and S_{22} satisfy the negligible condition. In Fig.1, the available power which can be obtained from only the radiation resistance R_r and the source voltage V_s is given by $V_s/(4R_r)$. If the compensation impedance is synthesized so as to match conjugately with R_r, the gain relative to the available power($V_s/(4R_r)$) becomes R_L/R_r. Then, the received signal is amplified when $R_L > R_r$.

5. Conclusion

In this paper, a synthesis method for an arbitrary impedance of a small antenna has been proposed. It has become clear that it is easy to realize the compensation impedance by using ordinary amplifier design techniques.

References

[1] Merrill, J.L.: "Theory of the negative impedance converters", Bell Syst.Tech.J., 30, pp88-109(1951).

[2] Yanagisawa, T.: "RC active network using current inversion type negative impedance converter", IRE Trans. CT-4, pp.140-144(1957).

[3] R.F.Shea. : "Amplifier Handbook", Chap.4, McGraw-Hill (1966).

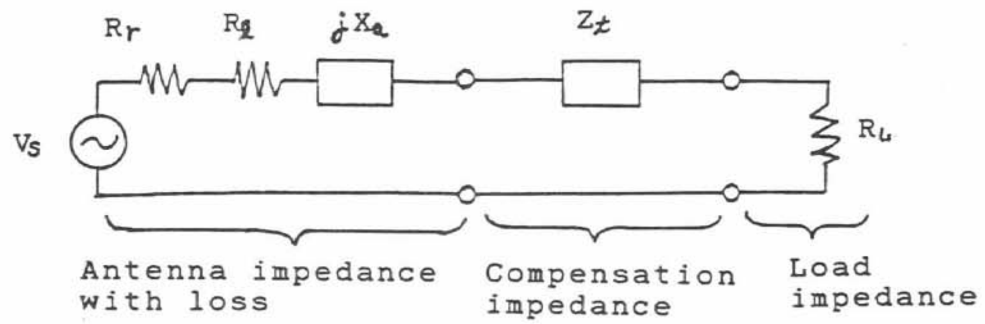
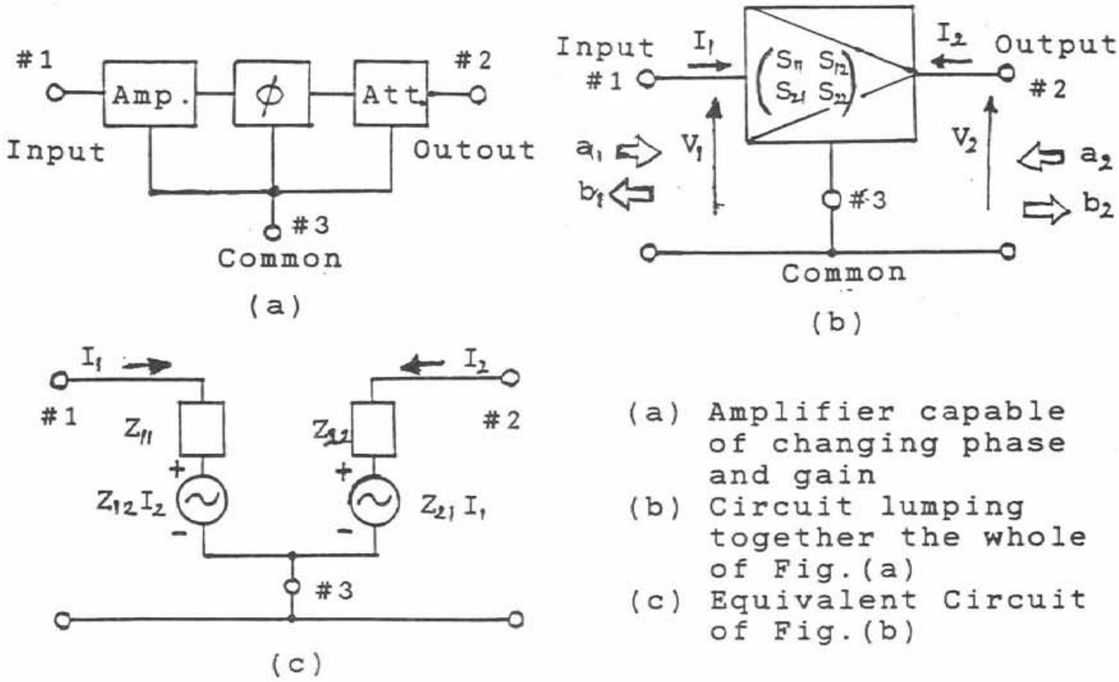


Fig.1. Equivalent Circuit of Small Antenna.



(a) Amplifier capable of changing phase and gain
(b) Circuit lumping together the whole of Fig.(a)
(c) Equivalent Circuit of Fig.(b)

Fig.2. Impedance Synthesis Circuit.

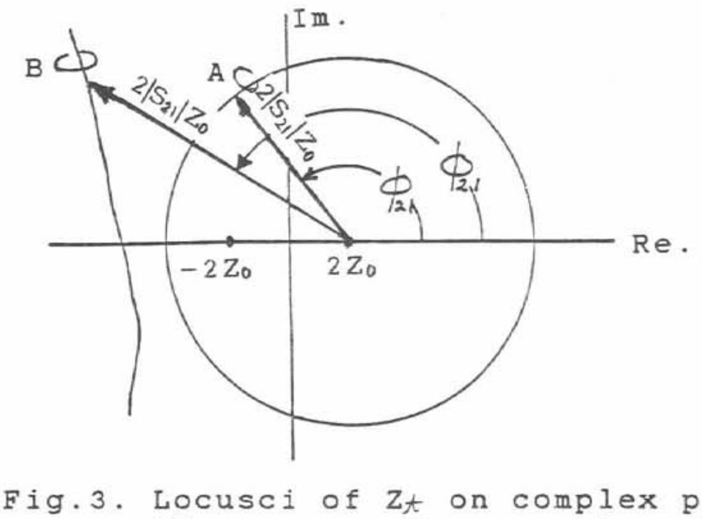


Fig.3. Locusci of Z_t on complex plane.
(Two cases of curves A and B)