Reduction of Group Delay of Microstrip Lines with a Non-Foster Negative Capacitance for Future Epsilon Near Zero / Epsilon Negative Applications

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Recently, non-Foster elements (a negative capacitance and inductance) have been focused in antenna fields due to their potential as a wideband matching network for electrically small antennas beyond theoretical limitation (Chu limit). However, the non-Foster elements also have another interesting aspect in metamaterial field.

Let's consider a transmission line (TL) whose effective permittivity and permeability are given by ε_{r_MSL} and μ_{r_MSL}. When a capacitor with a negative capacitance $C_{Non\text{-}F.}$ is installed in parallel to the TL with length l as shown in Fig. 1, an equivalent effective permittivity of the TL is expressed by $\varepsilon_r = C_{MSL}' + C_{Non\text{-}F.} / l$, where C_{MSL}' is a unit-length capacitance of the host TL. Since the $C_{Non\text{-}F.}$ has a negative value, the ε_r can be reduced to be less than 1 (epsilon near zero, ENZ) or negative (epsilon negative, ENG) by choosing an appropriate negative capacitance.

To demonstrate such a metamaterial-like response, two microstrip lines (MSLs) with l=1.0 mm and a line width of 3.0 mm are fabricated by using a FR4 substrate with a substrate permittivity of ε_r=4.4 and a thickness of 1.6 mm. Among them, one is a normal MSL and the other is a MSL with a negative capacitance as presented in Fig.1. The non-Foster negative capacitance is generated by using a Livill-type negative impedance converter (NIC) (*Ref. K.S. Song, Dissertation of Elec.Comp.Eng., The Ohio State University, 2011*) with a capacitor 100pF as a sign-reversed impedance element. Measured group delay and scattering parameters are presented in Figs. 2a and 2b, respectively. It can be confirmed that the group delay of the MSL with $C_{Non\text{-}F.}$ is reduced or equal to that of the single MSL in a frequency range from 400MHz to 800MHz where the NIC generates a negative capacitance. From Fig. 2b, an insertion loss of the MSL with $C_{Non\text{-}F.}$ is increased at these frequency due to absorption by an undesired resistance of the NIC induced simultaneously with the negative capacitance. Though the demonstrated circuit has not been optimized perfectly, the result ensures the possibility to realize ENZ or ENG metamaterials by using non-Foster elements.

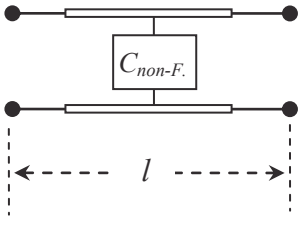
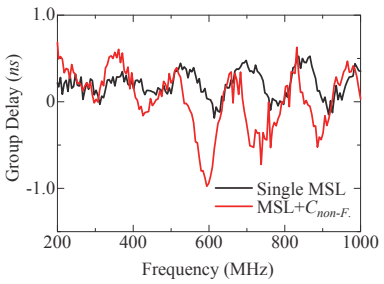
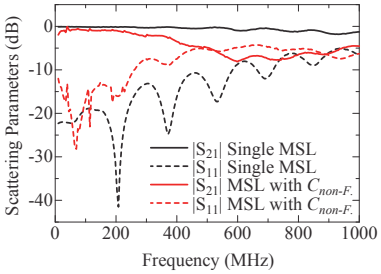


Fig. 1 A TL with a negative capacitance.



(a)



(b)

Fig.2 Measured group delay (a) and S parameters (b).