Microwave Group Delay Time Adjuster Using Parallel Resonator

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***Abstract*—This letter describes the design of a group delay time adjuster (GDTA) using a parallel resonator. The GDTA consists of a variable capacitor and a variable equivalent inductor. These components are controlled by two bias voltages separately. The variable equivalent inductor is realized using a high impedance transmission line terminated with the variable capacitor. Group delay time can be adjusted by varying the capacitance and the inductance while keeping the fixed resonance frequency. When the proposed GDTA is fabricated on the Korean RFID frequency band (908.5–914 MHz), we could obtain about 3 ns group delay time variation with excellent flatness.**

***Index Terms*—Group delay, resonance circuit, varactor diode, variable inductor.**

I. Introduction

A SYSTEM performance is limited due to the nonlinearity. The nonlinearity of a system can be explained as AM-to-AM, AM-to-PM, intermodulation distortion, and adjacent channel power ratio, etc. Several linearizing techniques have been introduced to overcome these nonlinearities [1], [2]. When a predistortion or a feedforward technique is applied to the nonlinear system, group delay time matching as well as amplitude and out-of-phase matching are very important. A variable attenuator and a phase shifter are widely used for the magnitude and the phase control [3], [4].

Moreover, a feedback interference signal originated from transmitter (Tx) antenna of the same site deteriorates the performance of receiver (Rx) system and result in the co-channel interference in the repeating system. The delay time of the co-channel interferer from Tx to Rx is different case by case and due to the environmental condition. The amplitude, phase, and electrical delay time of the correction signal are adjusted to cancel the broadband interferer effectively [5], [6].

Until now there have been few GDTA in microwave circuits. The GDTA which consists of different paths having different physical length was introduced [7]. However, the previous GDTA could not control the group delay time adaptively. In this letter, the GDTA which controls group delay time is proposed. The proposed GDTA can play a key role in a number of applications which require group delay time compensation for a proper group delay matching.

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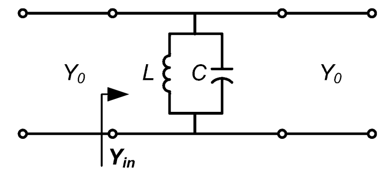


Fig. 1. Shunt resonance circuit.

II. Adjustable Group Delay Theory

A group delay gives the measure of how long it takes to traverse a system. In general, the changing rate of the total phase shift with respect to angular frequency is called the group delay (G.D.), defined as [8]

$$\text{G.D.} = -\frac{d\varphi}{d\omega} \tag{1}$$

where φ and ω denote the total phase shift and the angular frequency, respectively. Also, the group delay flatness in the operating frequency band is an important parameter for observing phase linearity of a receiver system, transmitted signal, and so on.

We need to analyze a resonant circuit shown in Fig. 1. The input admittance of the resonant circuit is expressed as (2) and the transmission characteristic can be expressed as (3)

$$Y_{\text{in}} = Y_0 + j\left(\omega C - \frac{1}{\omega L}\right) \tag{2}$$

$$S_{21} = \frac{2Y_0}{\sqrt{4Y_0^2 + (\omega C - 1/\omega L)^2}} \times \exp\left(j\left(\tan^{-1}\frac{1-\omega^2 LC}{2\omega L Y_0}\right)\right). \tag{3}$$

We derived (4), the differential phase component of transmission coefficient with respect to angular frequency, from (3). If we maintain the particular resonance frequency, $\omega_0^2 LC = 1$, of the parallel resonator, the magnitude, and the phase coefficient would be maintained constantly. However, the group delay time can be expressed as

$$\text{G.D.} = \frac{2Y_0 L\left(1+\omega^2 LC\right)}{4\omega^2 L^2 Y_0^2 + (1-\omega^2 LC)} = \frac{1}{\omega_0^2 Y_0 L} = CZ_0. \tag{4}$$

From (4), the group delay time increases proportional to the capacitance. On the contrary, as the inductance increases, group delay time decreases, proving the inverse proportionality to the inductance. Keeping the fixed resonant frequency, the group delay time can be adjusted by the several combinations of a capacitance and an inductance.

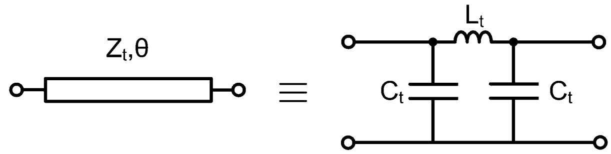


Fig. 2. Transmission line and a lumped element equivalent circuit.

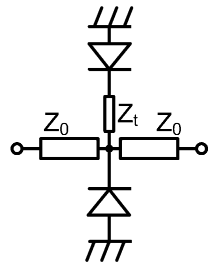


Fig. 3. Proposed GDTA unit.

III. Implementation and Measurement of the GDTA

A. Varactor Diode Measurement

A varactor diode is a semiconductor device that is widely used in many applications where we require a variable capacitance. The operation of the varactor diode is based on the fact that a reverse biased PN junction acts as a variable capacitor. The used diode capacitance of 1T362 of Sony versus reverse voltage has a variation of about 2.3 to 100 pF.

B. A Variable Equivalent Inductor and the GDTA Unit

There are few variable inductors in microwave devices. Even though there is an active inductor using a gyrator structure that can change an inductance, a quality factor (Q-factor) is not high enough and is changed according to the control voltage [9]. For that reason, the active inductor is not yet widely used. The series combination of lumped inductor and varactor diode can be used as a variable equivalent inductor. However, since it is difficult to fabricate high Q inductors with small tolerance, the combination of varactor diode and lumped inductor is not suitable. A transmission line terminated with the varactor can be also used as the variable inductor. However, the physical length of transmission line is too long in case of the low operating frequency.

In this work, a high impedance transmission line terminated with the varactor is used to implement the variable inductor. Fig. 2 shows the lumped element equivalent circuit of the transmission line. Z_t and θ are characteristic impedance and electrical length of the transmission line, respectively. The values of the equivalent lumped elements are represented as

$$L_t = \frac{Z_t \sin\theta}{\omega}, \quad C_t = \frac{1-\cos\theta}{Z_t \omega \sin\theta}. \tag{5}$$

Using the varactor diode and the proposed variable equivalent inductor, we design the GDTA unit shown in Fig. 3. The varactor diode is operated as the variable capacitance, and the transmission line terminated with the varactor diode is operated as the variable equivalent inductor.

The transformation procedure of the variable equivalent inductor is depicted at Fig. 4. Capacitor C_1 denotes the variable capacitance, and C_2 is used for the variable equivalent inductor with the high impedance transmission line, respectively. We replaced high impedance transmission line with lumped element equivalent circuit as shown in Fig. 4(a) and (b). Since C_2 shares node A with C_t, and C_1 shares node B with C_t, we can substitute those pairs of capacitors with C' and $C_1 + C_t$, as shown in Fig. 4(c). Finally, $C_1 + C_t$ can be represented as C'', and series connection of L_t and C' can be substituted with L'. Equation (6) shows the equivalent reactance of the transmission line terminated with the varactor diode. As long as the equivalent reactance (X_L) is positive, it has an inductive characteristic. Therefore, as C' is varied, we can obtain the variable inductance

$$X_L = \frac{\omega_0^2 L_t C' - 1}{\omega_0 C'}. \tag{6}$$

The value of the variable capacitor and inductor are controlled by two separate bias voltages, and they must satisfy the fixed resonance condition. The measured result of the proposed GDTA unit tested at 911 MHz is shown in Table I.

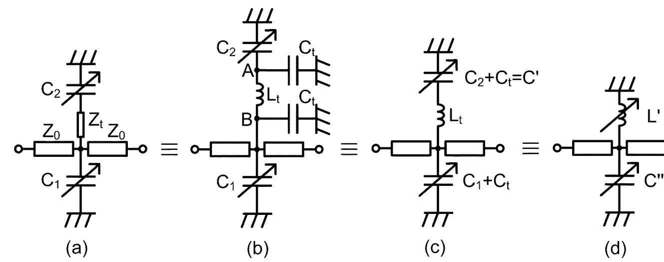


Fig. 4. Equivalent circuit of the GDTA using the transmission line.

TABLE I
GDTA Unit Measurement (at 911 MHz)

G.D. **[ns]**	**S21[dB]**	**S11[dB]**
0.420	-0.23	-31.40
1.420	-0.77	-21.30
2.468	-1.45	-16.30
3.479	-2.20	-13.10

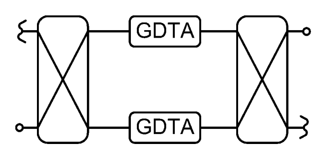


Fig. 5. Block of the proposed balanced GDTA.

C. Balanced GDTA

In order to obtain better reflection characteristics of the GDTA, a balanced GDTA structure is proposed and shown in Figs. 5 and 6. It is composed of two hybrid couplers (RF Power, S03A888N1) and two GDTA units. The overall circuit size is 79×39 [mm]. The implemented GDTA is tested on RFID Korean frequency band (908.5–914 MHz). The group delay measurement of the proposed balanced GDTA is represented at Table II and Fig. 7.

Although we could obtain more group delay time variance more than 3 ns, the transmission and the group delay time flat-

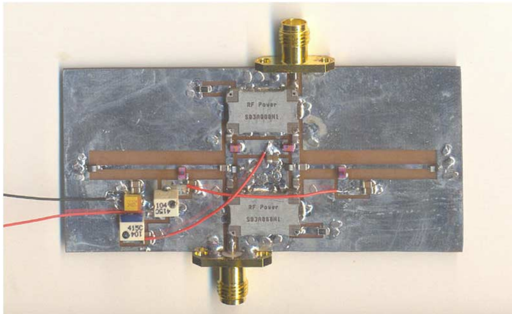
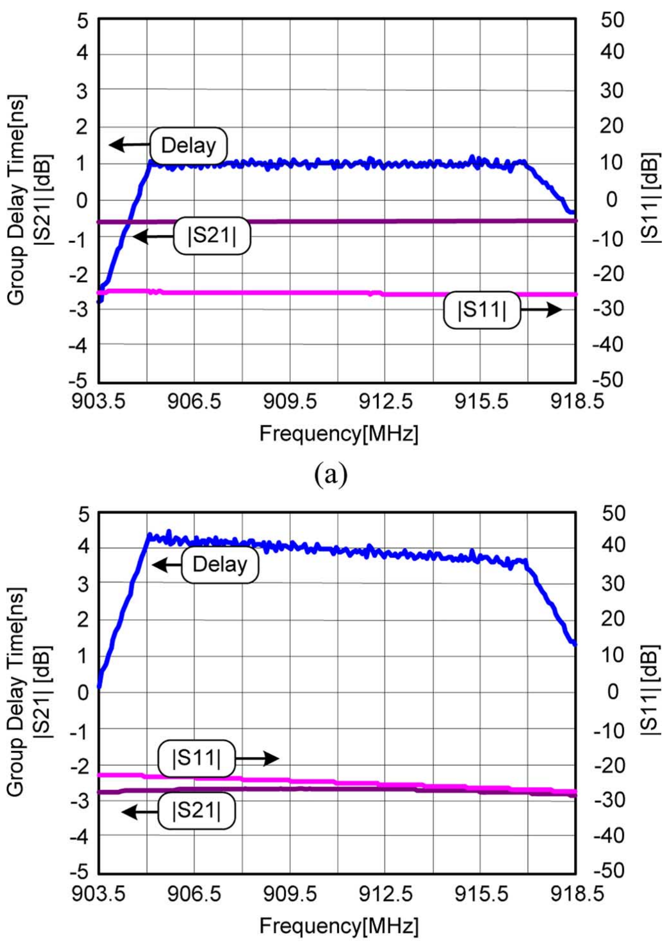


Fig. 6. Fabricated balanced GDTA.



(a)

(b)

Fig. 7. Electrical characteristics of the balanced GDTA. (a) Minimum group delay time. (b) Adjustable group delay time.

TABLE II
BALANCED GDTA MEASUREMENT RESULTS

G.D.[ns]			S21[dB]			S11,max [dB]	Control Voltage[V]	
908.5 MHz	911 MHz	914 MHz	908.5 MHz	911 MHz	914 MHz		V_C	V_L
1.005	1.041	1.025	-0.65	-0.64	-0.64	-25.65	25.0	0.0
2.000	2.010	1.970	-1.36	-1.37	-1.39	-26.74	10.0	14.4
3.051	3.077	2.986	-1.96	-1.95	-1.95	-24.84	8.3	17.5
4.021	3.938	3.792	-2.68	-2.68	-2.71	-24.41	7.0	19.8

ness in the high group delay time region are in a trade-off relation so that we have no choice but to limit the actual variation range as 3 ns. In that case, the magnitude flatness is less than 0.1 dB in the pass band and the maximum reflection coefficient is about -24.4 dB, satisfactory results to be applied to the systems where the group delay time matching with good flatness is essential.

IV. CONCLUSION

We designed a new GDTA unit which can control the group delay time of a signal using the parallel resonant circuit. Keeping the fixed resonance frequency, the group delay time can be adjusted by the combination of values of capacitance and inductance. The fabricated balance GDTA improves the poor reflection characteristic of the single GDTA unit and presents the group delay time variation of about 3 ns. Now we have a plan to apply the GDTA to the wireless communication systems such as the co-channel interference cancellation technique and feedforward linearization. We think that the proposed GDTA will contribute not only to the improvement of the quality of a communication, but to the simplification of the group delay time tuning procedure of a communication system.

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