



Microwave Journal

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THE FORWARD LOOK

RF Components and Systems

in microwave plumbing for

By TORE N. ANDERSON
AIRTRON INC.
LINDEN, NEW JERSEY



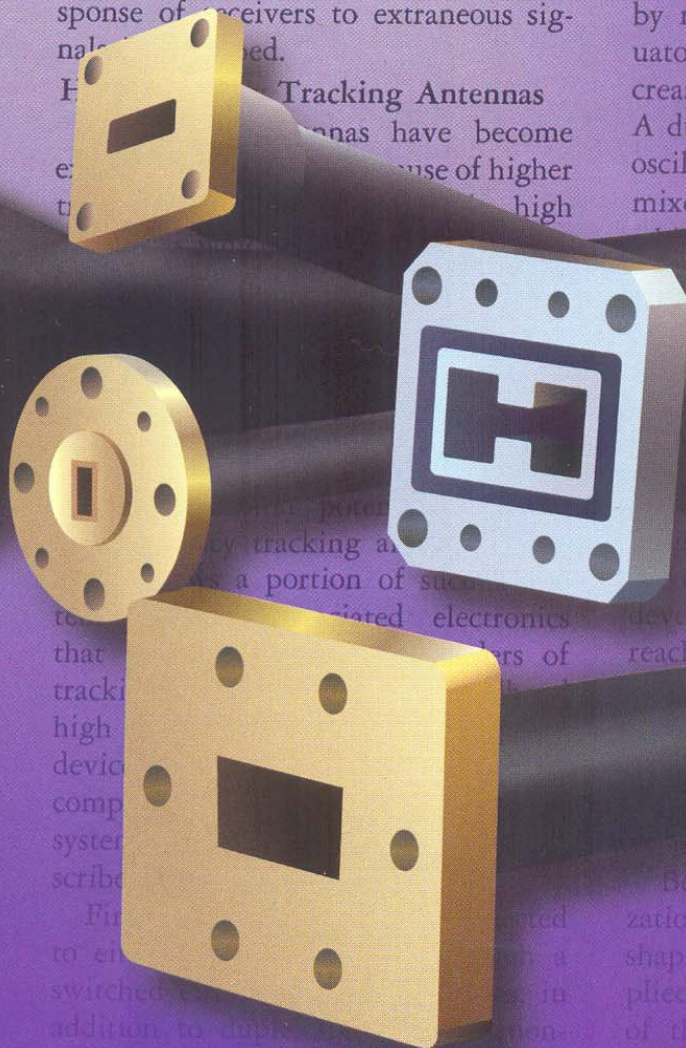
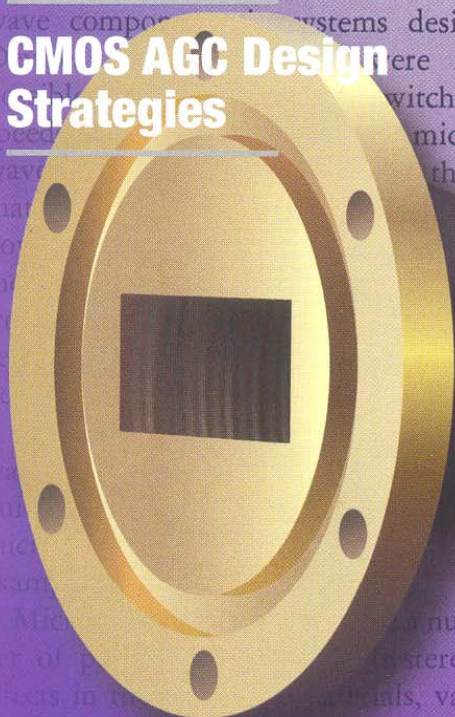
Microwave Plumbing for Systems Applications

A Passion for Plumbing CMOS AGC Design Strategies

and harmonic reduction for microwave systems. A number of the techniques which are being developed to reduce spurious radiation and the response of receivers to extraneous signals are described.

Tracking Antennas
Tracking antennas have become essential for the use of higher frequency antennas. High

power divider, local oscillator itself, and the output level by means of a variable attenuator similar to the one increasing the dynamic range. A dual isolator is included in the oscillator feed legs which mixers in the



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DESIGN OF A MICROWAVE GROUP DELAY TIME ADJUSTER AND ITS APPLICATION TO A FEEDFORWARD POWER AMPLIFIER

This article presents a design method for a microwave group delay time adjuster (GDTA) and its application to a feedforward (FFW) power amplifier (PA). The GDTA consists of a variable capacitor and a variable equivalent inductor. The variable equivalent inductor is realized using a high impedance transmission line terminated with a variable capacitor. These components are controlled by two separate bias voltages. The group delay time can be adjusted by varying the capacitance and inductance while keeping a fixed resonance frequency. The proposed GDTA is fabricated for the Korean RFID frequency band (908.5 to 914 MHz). A group delay time variation of approximately 3 ns is obtained with satisfying transmission flatness. When the proposed GDTA was applied to the base station FFW PA system, the loop group delay time matching was much easier and required less effort and time, while achieving an excellent linearization result compared to the conventional FFW PA system.

As linear modulation and demodulation is adopted in communication systems for spectrum efficiency, the system performance is limited due to nonlinearity, particularly in the power amplifier. The nonlinearity of a system can be explained as AM-AM, AM-PM, intermodulation distortion (IMD) and adjacent channel leakage ratio (ACLR). Several linearizing techniques have been introduced to overcome these nonlinearities.¹⁻³ When a digital/analog predistortion or a FFW technique is applied to the nonlinear system, a group delay time matching as well as amplitude and out-of-phase matching are critical. While a variable attenuator and a phase shifter are widely used for the magnitude and phase

control, there are few circuits available for control of the group delay time.⁴

Moreover, a feedback receiving signal, originating from the transmitter (Tx) antenna of the same site, deteriorates the performance of

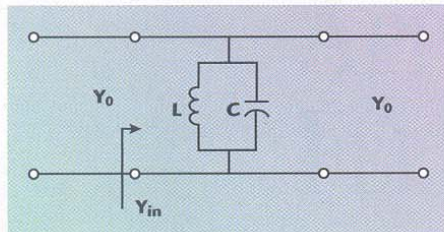
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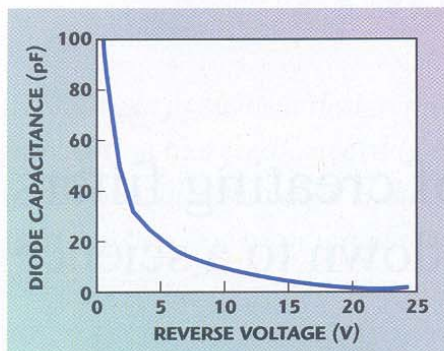
CHUL DONG KIM
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the received (Rx) signal and results in co-channel interference in the repeater system. The delay time of the co-channel interferer from Tx to Rx is different, case by case, and due to environmental conditions. The amplitude, phase and electrical delay time of the correction signal should be adjusted to effectively cancel the broadband interferer.^{5,6}

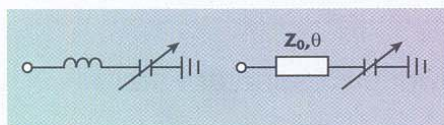
Until now, there have been few microwave circuit GDTAs. A GDTA, consisting of different paths having different physical length, was introduced.⁷ However, it could not control



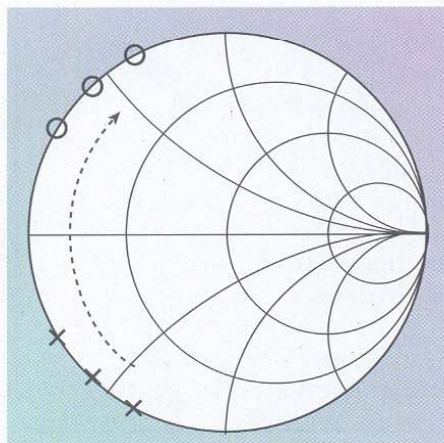
▲ Fig. 1 Shunt resonant circuit.



▲ Fig. 2 Measured capacitance of the Sony 1T362 varactor diode.



▲ Fig. 3 A virtual variable inductor using a transmission line.



▲ Fig. 4 Transformation from a capacitive to an inductive characteristic.

the group delay continuously. In this article, a microwave GDTA is proposed that is capable of continuous group delay time control. The proposed GDTA is expected to play a key role in a number of applications where group delay time compensation is critical for broadband signal cancellation. To show its validity, a GDTA and base station FFW PA system were designed, fabricated and measured, using the proposed GDTA as an application example.

ADJUSTABLE GROUP DELAY THEORY

A group delay gives the measure of how long it takes a signal to propagate through a system. In general, the rate of change of the total phase shift with respect to angular frequency is called the group delay (GD), and is defined as⁸

$$GD = -\frac{d\phi}{d\omega} \tag{1}$$

where

$d\phi$ = total phase shift
 ω = angular frequency

Also, the group delay flatness in the operating frequency band is an important parameter for observing the phase linearity of a receiver system, transmitted signal and so on.

To find the method to control the group delay, it is necessary to analyze a shunt resonance circuit, as shown in **Figure 1**. The input admittance of the resonance circuit is expressed as

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

and the transmission characteristic can be expressed as

$$S_{21} = \frac{2Y_0}{\sqrt{4Y_0^2 + (\omega C - 1/\omega L)^2}} \exp\left(j\left(\tan^{-1} \frac{1 - \omega^2 LC}{2\omega LY_0}\right)\right) \tag{3}$$

If the particular resonance frequency, $\omega_0^2 LC = 1$ of the parallel resonator is maintained, the magnitude and the phase coefficient would be kept constant. Then GD, the differential phase component of the transmission coefficient with respect to

the angular frequency, can be derived from Equation 4 at the particular resonance frequency, by using Equations 1 and 3.

$$GD = \frac{2Y_0 L (1 + \omega^2 LC)}{4\omega^2 L^2 Y_0^2 + (1 - \omega^2 LC)} \bigg|_{\omega_0^2 LC = 1} = \frac{1}{\omega_0^2 Y_0 L} = CZ_0 \tag{4}$$

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

IMPLEMENTATION AND MEASUREMENT OF THE GDTA Varactor Diode Measurement

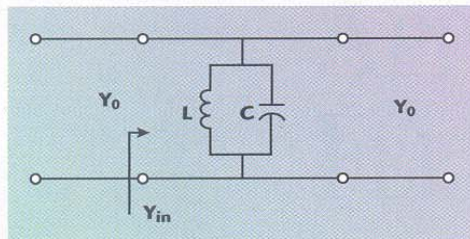
A varactor diode is a semiconductor device that is widely used in many applications where a variable capacitance is required. The operation of the varactor diode is based on the fact that a reverse biased PN junction acts as a variable capacitor. The diode capacitance versus reverse voltage of the Sony 1T362 device used has a variation of approximately 2.3 to 100 pF, as shown in **Figure 2**.

Variable Equivalent Inductor and the GDTA Unit

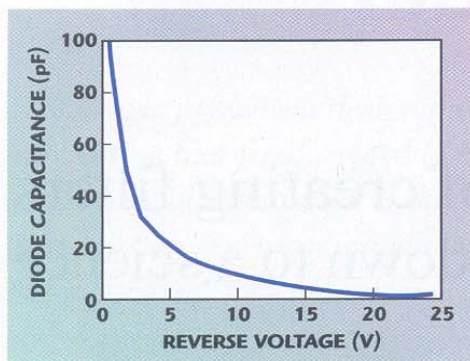
There are few variable inductors in microwave devices. Even though there is an active inductor using a gyrator structure that can change the inductance, the quality factor (Q) is not high enough and changes according to the control voltage.^{9,10} For that reason, the active inductor is not yet widely used. The series combination of a lumped inductor and varactor diode can be used as a variable equivalent inductor. Since it is difficult to fabricate high Q inductors with a small tolerance, however, the combination of varactor diode and lumped inductor is not suitable. A transmission line of characteristic impedance Z_0 , terminated with a varactor, can also be used as a variable inductor, as shown in **Figure 3**. A transmission line characteristic shifts from capacitive to inductive, as shown in **Figure 4**. However, the

the received (Rx) signal and results in co-channel interference in the repeater system. The delay time of the co-channel interferer from Tx to Rx is different, case by case, and due to environmental conditions. The amplitude, phase and electrical delay time of the correction signal should be adjusted to effectively cancel the broadband interferer.^{5,6}

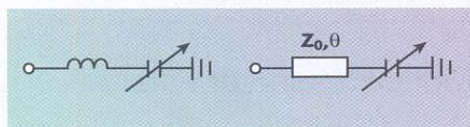
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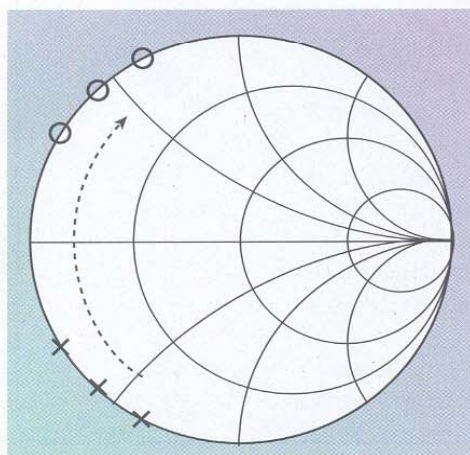
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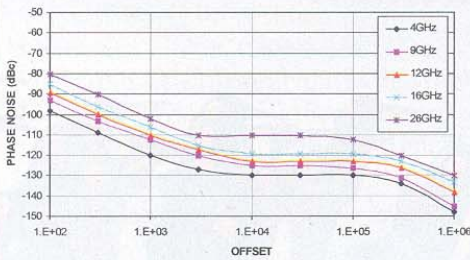
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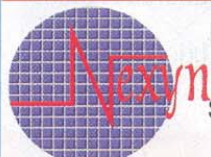
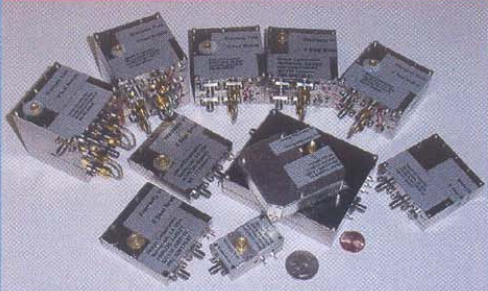
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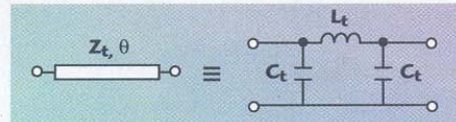
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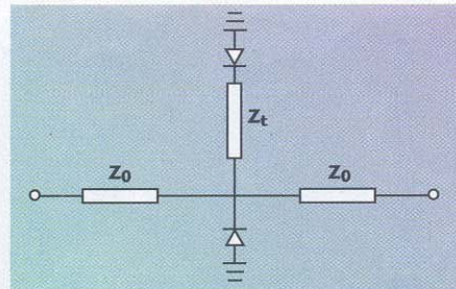
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physical length of a transmission line is too long in case of a low operating frequency.

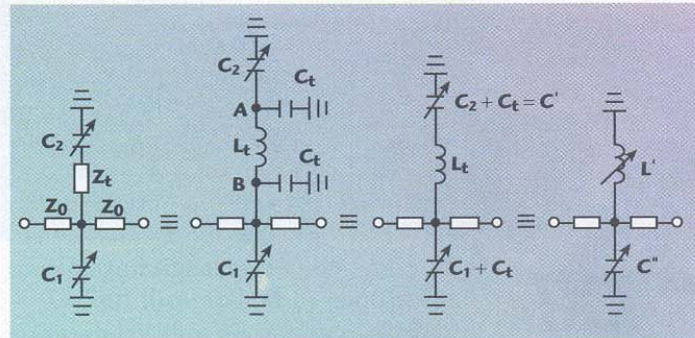
In this work, a high impedance transmission line, terminated with a varactor, is used to implement the variable inductor. **Figure 5** shows the lumped element equivalent circuit of the transmission line, where Z_t and θ



▲ Fig. 5 A high impedance transmission line and its equivalent circuit.



▲ Fig. 6 The proposed GDTA unit.



▲ Fig. 7 Equivalent circuit of the unit GDTA using a high impedance transmission line.

are the characteristic impedance and electrical length of the transmission line, respectively. The values of the equivalent lumped elements are

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

Using the varactor diode and the proposed variable equivalent inductor, the GDTA unit shown in **Figure 6** was designed. The varactor diode is operated as the variable capacitor, and the high impedance transmission line terminated with the varactor diode is operated as the variable equivalent inductor.

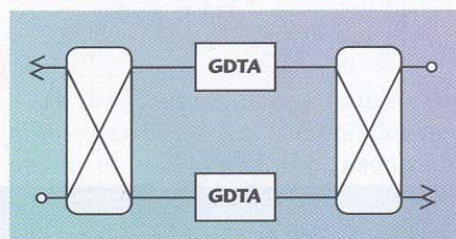
The transformation procedure of the variable equivalent inductor is depicted in **Figure 7**. The capacitor C_1 denotes the variable capacitance and C_2 is used for the variable equivalent inductor with the high impedance transmission line, respectively. The high impedance transmission line was replaced with the lumped element

equivalent circuit. Since C_2 shares node A with C_t and C_1 shares node B with C_t , these pairs of capacitors can be substituted with C' and $C_2 + C_t$. Finally, $C_1 + C_t$ can be represented as C'' and the series connection of L_t and C' can be substituted with L' . Equation 6

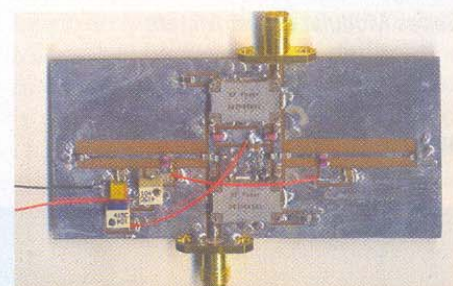
shows the equivalent reactance of the transmission line terminated with the varactor diode. As long as the equivalent reactance (X_L) is positive, it has an inductive characteristic. Therefore, as C' is varied, a variable inductance can be obtained.

$$X_L = \frac{\omega_0^2 L_t C' - 1}{\omega_0 C'} \quad (6)$$

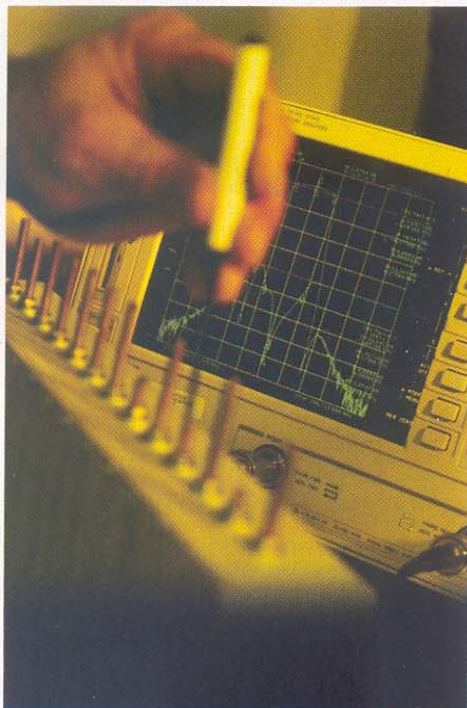
Group Delay (ns)	S_{21} (dB)	S_{11} (dB)
0.420	-0.23	-31.40
1.420	-0.77	-21.30
2.468	-1.45	-16.30
3.479	-2.20	-13.10



▲ Fig. 8 Block diagram of the balanced GDTA using two unit GDTA's.



▲ Fig. 9 The fabricated balanced GDTA.



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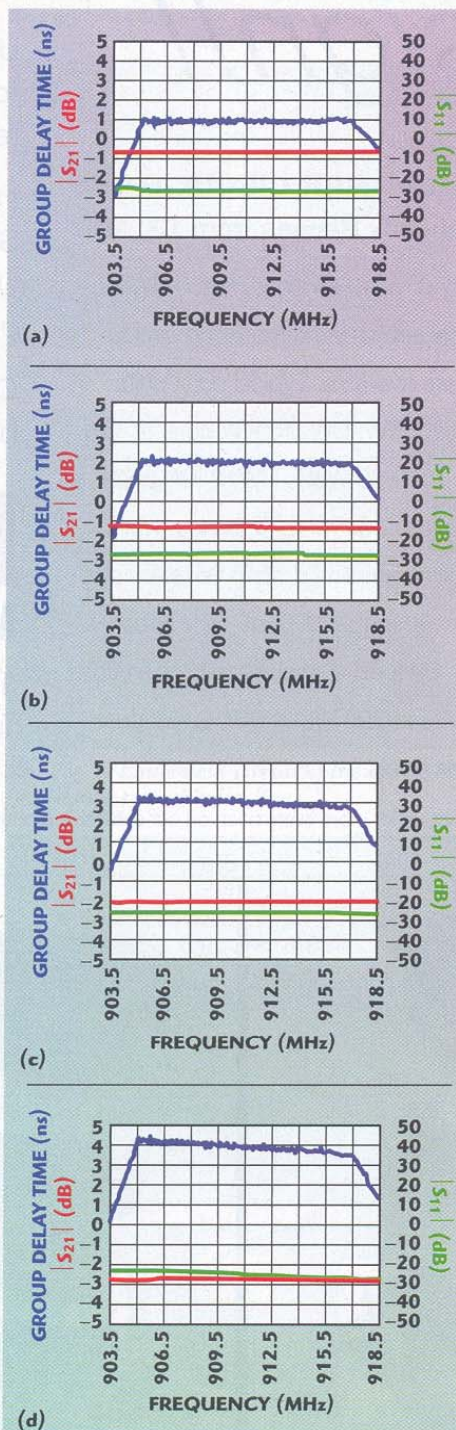


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TABLE II

MEASURED RESULTS FOR THE BALANCED GDTA

Group Delay (ns)			S_{21} (dB)			S_{11} 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



▲ Fig. 10 Electrical characteristics of the balanced GDTA at 1 ns (a), 2 ns (b), 3 ns (c) and 4 ns (d).

The values of the variable capacitor and inductor are controlled by two separate bias voltages that must satisfy the fixed resonance condition. The measured results of the proposed GDTA unit, tested at 911 MHz, are shown in **Table 1**. As GD is increased, the reflection characteristics are getting increasingly worse, due to the parasitic component of the varactor diode.

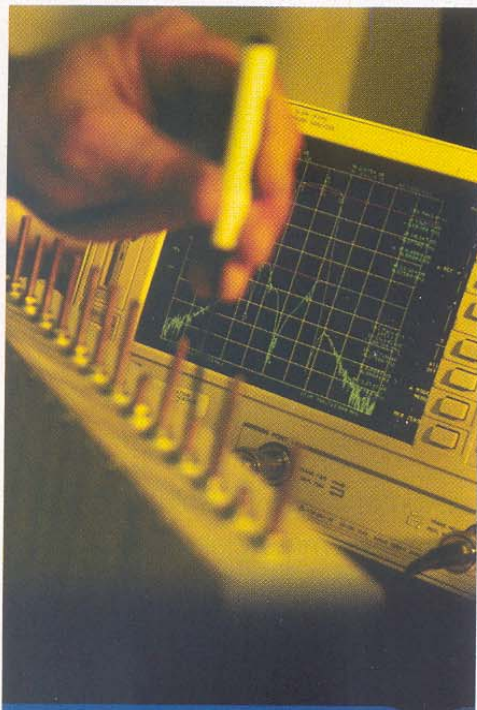
The Balanced GDTA

In order to obtain better reflection characteristics of the GDTA, a balanced GDTA structure is proposed and shown in **Figure 8**. It is composed of two hybrid couplers (RF Power, S03A888N1) and two unit GDAs. The overall circuit size is 79 × 39 mm, as shown in **Figure 9**. The implemented GDTA was tested in the Korean RFID frequency band (908.5 to 914.0 MHz). The group delay measurements of the proposed balanced GDTA are shown in **Table 2** and **Figure 10**.

Although a group delay time variance greater than 3 ns could be obtained, the transmission and the group delay time flatness in the high group delay time region are in a trade-off relationship, so that there was no choice but to limit the actual variation range to 3 ns. In that case, the magnitude flatness is less than 0.1 dB in the pass band and the maximum reflection coefficient is approximately -24.4 dB. These satisfactory results can be applied to systems where the group delay time matching with good flatness is critical.

BASE STATION FFW PA DESIGN USING THE PROPOSED GDTA

To obtain broadband signal cancellation, broadband amplitude, out-of-phase and group delay matching are



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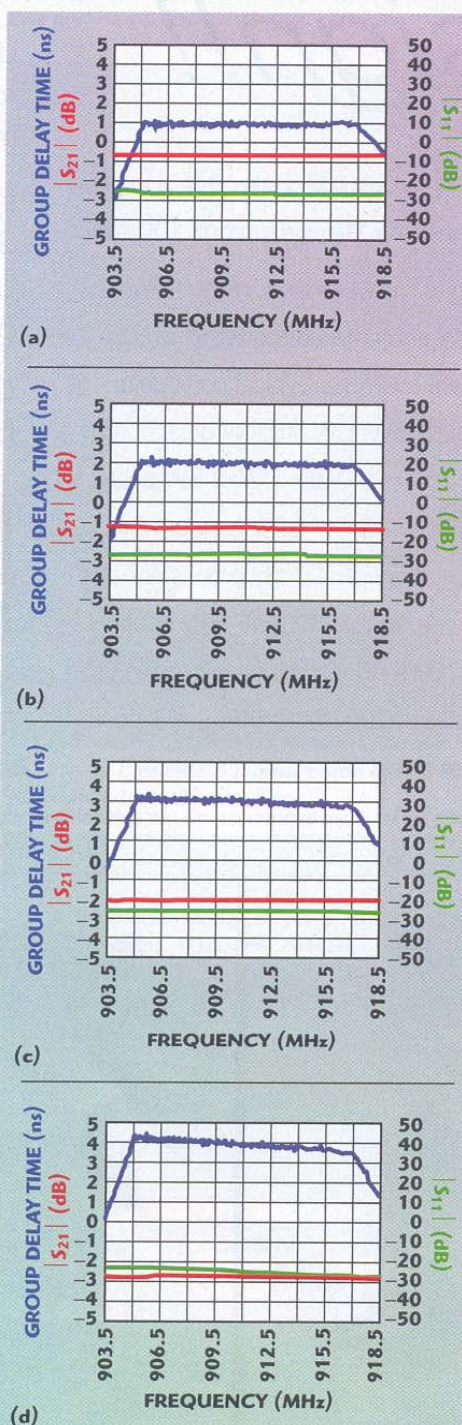
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BASE STATION FFW PA DESIGN USING THE PROPOSED GDTA

To obtain broadband signal cancellation, broadband amplitude, out-of-phase and group delay matching are

at an average output power of 40 dBm is shown before and after cancellation. The ACLR at a 3.125 MHz offset is -52.12 dBc, improved by approximately 17.2 dB by the cancellation. The amount of improvement is smaller than expected from the results shown on the network analyzer because of the limitation of the measurement setup. The proposed system shows excellent linearity throughout the output dynamic range.

CONCLUSION

A new GDTA unit was designed that can control the group delay time of a signal using a parallel resonance circuit. Keeping the resonance frequency fixed, the group delay time can be adjusted by the combination of values of capacitance and inductance through a simple voltage control. The fabricated balanced GDTA improves the poor reflection characteristics of the single GDTA unit and

offers a group delay time variation of approximately 3 ns. Also, the validity of the proposed GDTA was established by applying the circuit to a feedforward linearization. The pro-

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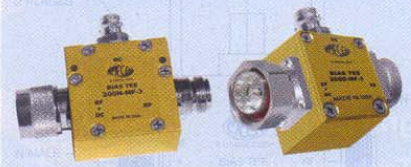
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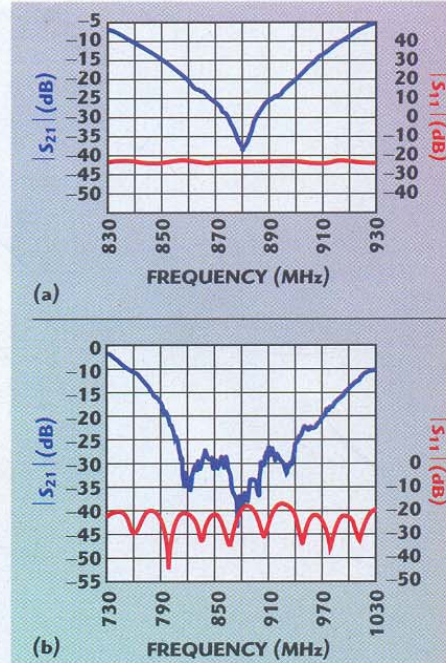


Fig. 13 Carrier cancellation loop suppression of the FFW PA using the GDTA (a) and IMD cancellation loop (b).

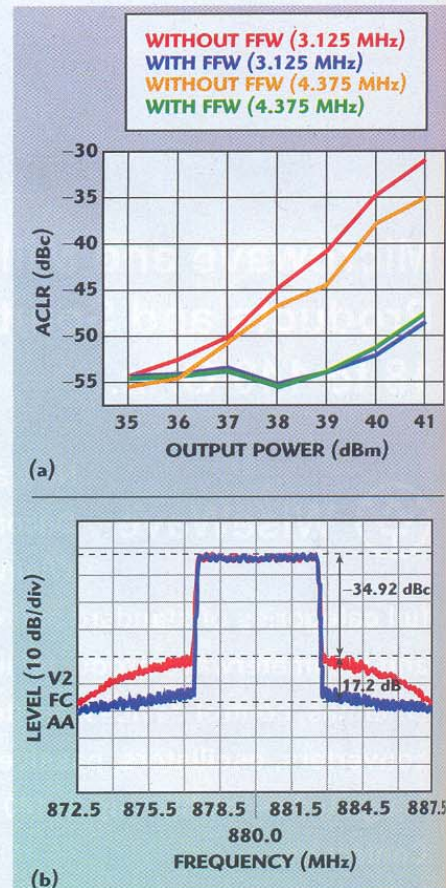


Fig. 14 Measured ACLR characteristics over the dynamic range (a) and power spectral density of the FFW PA using GDTA (b), with and without the FFW loop.

posed GDTA will contribute not only to the improvement of the quality of a communication, but also to the simplification of the group delay time tuning procedure of a communication system. ■

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