An Antenna Switch MMIC Using E/D Mode p-HEMT for GSM/DCS/PCS/WCDMA Bands Application

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***Abstract* — A monolithic antenna switch IC using enhancement and depletion (E/D) - mode AlGaAs/InGaAs pseudomorphic high electron mobility transistors (p-HEMTs) has been developed for GSM/DCS/PCS/WCDMA band digital mobile communication systems. This antenna switch MMIC achieves a low insertion loss and small chip size using a single pole double throw (SPDT) switch for GSM and single pole 4 throw (SP4T) switch for other band configurations, as well as internal logic circuits with an E/D mode p-HEMTs process. This MMIC achieves an insertion loss of 0.21dB at 915MHz and 0.53dB at 1785MHz. The isolation to the RX ports is more than 30 dB, and the input power at 0.1 dB compression is over 36 dBm at +2.7 V operation.**

I. INTRODUCTION

Currently, various cellular-phone systems are in use throughout the world, and it has been hoped that one cellular handset could be used with all these systems. Actually, GSM/DCS dual band systems have become the standard in Europe. In recent years, additional multi-band systems such as quad-band, added PCS, and WCDMA, as well as GSM/DCS dual bands systems have been required.

Usually PIN diode switch modules are adopted for use as an antenna switch. However PIN diode switch modules tend to be quite large as they use many discrete PIN diodes and a strip line to change multiple signal paths. The antenna switch modules also need a logic circuit to change various paths, therefore requiring more mounting area. Furthermore, PIN diode switch modules need milliampere order current to switch high power signals. Therefore a GaAs switch MMIC, which is easy to integrate and has low power consumption, is required. A GaAs switch MMIC has been developed with similar or superior characteristics to the various PIN diode switch modules [1]-[3].

In this paper, we describe a newly developed antenna switch MMIC for GSM/DCS/PCS/WCDMA quad bands. The p-HEMTs process is employed for this antenna switch, because on-resistance (Ron) is lower than MES-FET at the same pinch-off voltage (Vgs(off)). To produce a small MMIC with a logic circuit, we have chosen the E/D mode p-HEMTs process.

II. DEVICE FABRICATION

Figure 1 shows a cross-section of the developed E/D mode p-HEMTs. This device has a conventional double doped and double heterojunction structure, an AlGaAs as barrier layer, and an InGaAs channel layer. The top layer is a heavily doped n^+-GaAs layer for ohmic contact. The gate electrode consisting of Pt/Ti/Pt/Au is deposited after etching the n^+-GaAs/n^+-AlGaAs layers. Using heat treatment, an underlying Pt is buried into the GaAs layer. Control of Vgs(off) of p-HEMTs is accomplished by varying the buried depth. Therefore, selection of a proper Pt thickness makes it possible to fabricate E/D mode p-HEMTs on the same wafer.

In the depletion mode p-HEMT, Vgs(off) is –0.6 V, Ron is 2.1 Ω·mm at Vg=0 V and breakdown voltage (BVgdo) is –20 V. These characteristics are suitable for a high-power switch MMIC. On the other hand, in the enhancement mode p-HEMT, Vgs(off) is +0.3 V, Ron is 1.9 Ω·mm at Vg=+0.9 V and BVgdo is –20 V. This enhancement mode p-HEMT is well suited for logic

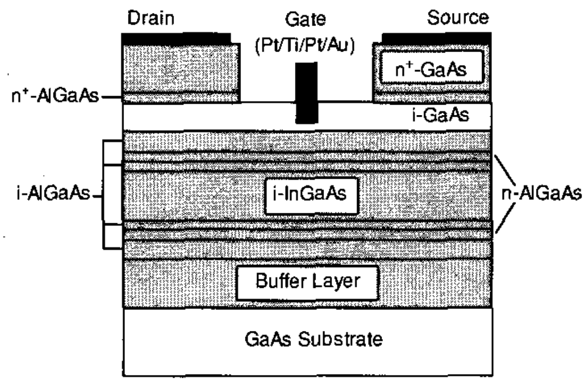

Fig.1. Cross-Section of Newly Developed E/D-mode p-HEMTs

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circuits because its Ron is as low as the Ron of the depletion mode p-HEMTs.

III. Circuit Design

A. Antenna Switch

At the beginning of development we investigated a configuration of a GSM/DCS/PCS/WCDMA band antenna switch. A single pole 6 throw (SP6T) switch could be used for this application. An SP6T switch operates from 800 MHz in GSM band to 2.2 GHz in WCDMA band. As this is a very wide frequency range, optimization of insertion loss is difficult. Usually, the gate width (Wgt) of FET is adjusted in order to optimize insertion loss. As the Wgt is larger, the Ron of FET is lower and the off-state capacitor (Coff) of FET is larger at same time. Wgt tend to be larger in the low band because the Ron of FET is more effective characteristics for insertion loss and smaller in the high band because the Coff is more effective characteristics for insertion loss, which means when only one switch IC operates over a wide frequency range, it can't be optimized for the entire range.

A GSM/DCS/PCS/WCDMA band cellular phone system requires that handsets receive both GSM signal and WCDMA signals at the same time. In this case, the antenna switch must be passed from the antenna to both the WCDMA and GSM RX terminals. If a SP6T switch is used and passed from the antenna to two terminals at the same time, the terminals will be connected to each other via the antenna switch. This will cause interference and the performance of the antenna switch will be degraded.

Therefore, we use an SPDT switch for the low band and an SP4T switch for the high band, and optimize insertion loss of each switch across its assigned frequencies. Figure 2 shows the configuration of the developed antenna switch MMIC. The SPDT switch is assigned GSM TX and GSM RX, and the SP4T switch is assigned DCS/PCS TX, DCS RX, PCS RX and WCDMA. For the TX/RX switch, the isolation characteristics between TX and RX are very important. Therefore, this MMIC has the shunt FETs at GSM RX, DCS RX, and PCS RX ports to ensure isolation.

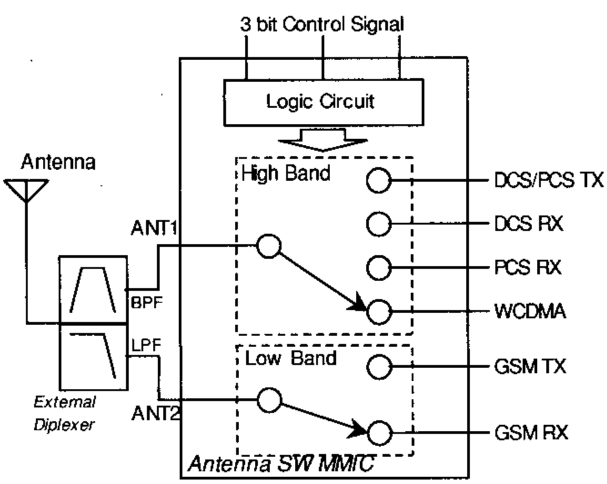

Fig.2. Schematic of Antenna Switch MMIC

This MMIC needs an external diplexer to divide signals for ANT1 and ANT2 when it is used in handsets (Fig.2). Therefore, the isolation factor between the SPDT and SP4T switches is very high. This allows a dual receive mode, such as GSM RX and WCDMA, with no signal loss. A diplexer usually consists of the LPF and the HPF. We consider that the HPF can be replaced with a BPF in order to suppress harmonics. Later in the paper, we demonstrate the antenna switch module using this antenna switch MMIC and the diplexer comprised of a LPF and a BPF in LTCC.

B. Logic Circuit

A logic circuit is necessary to control the SPDT and the SP4T switches. This logic circuit has 3-inputs (C-MOS compatible input signal terminals) and 7-outputs, to give five switch states, and uses a conventional direct coupling FET logic (DCFL). FETs used for DCFL are usually enhancement mode FETs since the current consumption of logic circuit must be reduced. The enhancement mode GaAs MESFETs have high Ron. Therefore, "L" level is up from 0 V, and an essential lower switch control voltage

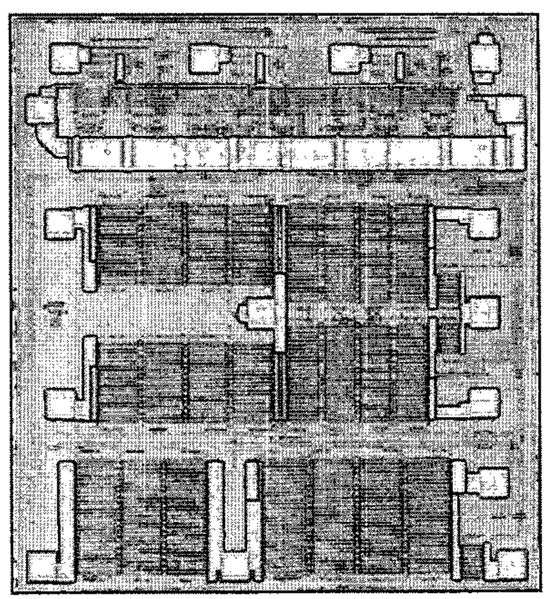

Fig.3. Photograph of Antenna Switch MMIC chip
Chip size: 1.43x1.57mm

("H"-"L") causes a maximum power handling of the switch MMIC to be reduced. Therefore, the enhancement and depletion mode p-HEMTs both show the same very low Ron, which is desirable for the logic circuit.

IV. Switch Performance

Figure 3 shows the photograph of the antenna switch MMIC chip with the logic circuit. The actual chip size is 1.43 x 1.57mm. The chip is assembled in a 20pin plastic package (3.4 x 3.6 x 0.6 mm).

Figure 4 shows the frequency response of our antenna switch MMIC in GSM TX mode. The insertion loss is 0.21 dB at 915 MHz. The isolation to the RX terminal with the shunt FET is 37 dB at 915 MHz. On the other hand, in the SP4T switch for high bands, the insertion loss is 0.53 dB at 1785 MHz. The isolation to the RX terminals with the shunt FET is 30 dB in DCS/PCS TX mode. These very low insertion losses are achieved by optimization of the SPDT switch for GSM bands and the SP4T switch for high bands.

Figure 5 shows the power transfer characteristics in GSM TX mode. The signal frequency is 915 MHz and the operation voltage (V_{DD}) is +2.7 V. The linearity is maintained up to an input power of 37dBm. This power handling capability is sufficient for GSM. In DCS/PCS TX mode, the linearity of the SP4T switch is maintained over an input power of 34 dBm. The input power at the 0.1 dB compression point ($P_{-0.1dB}$) is 36.0 dBm. This power handling capability is also sufficient for DCS and PCS.

The performance of the antenna switch MMIC is summarized in Table I. This MMIC has sufficient performance for GSM/DCS/PCS/WCDMA band application.

The MMIC chip is assembled on the LTCC package including the diplexer circuits. The package size of the antenna switch module is 3.8x3.8x1.6mm. Figure 6 shows

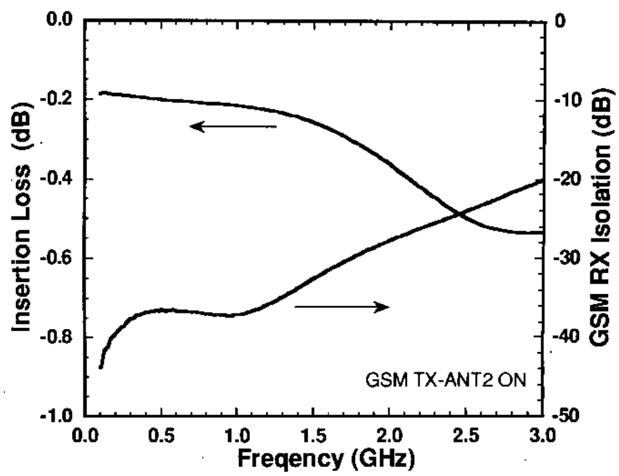

Fig.4. GSM TX-ANT2 Insertion Loss and GSM RX Isolation

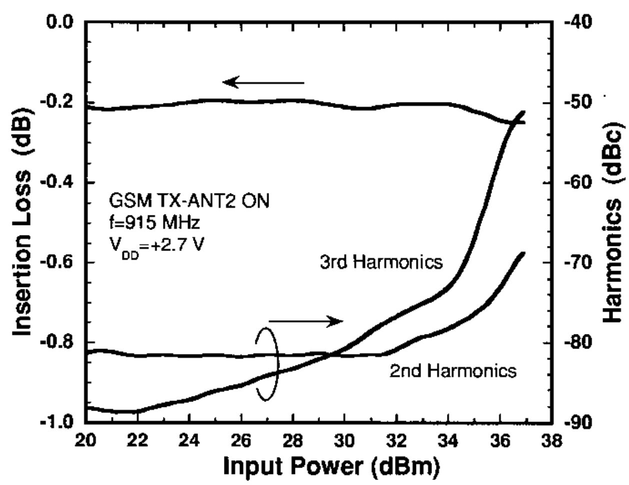

Fig.5. Power Transfer Characteristics in GSM TX mode

TABLE I Summary of Antenna Switch MMIC RF Characteristics

Pass	Condition		Loss (dB)	ISL (to RX) (dB)	$P_{-0.1dB}$	Harmonics (dBc)	
	Frequency	Pin				$2f_0$	$3f_0$
GSM TX-ANT2	915 MHz	35 dBm	0.21	37.2	>37 dBm	-76.8	-69.9
GSM RX-ANT2	960 MHz	0 dBm	0.33	-	-	-	-
DCS/PCS TX-ANT1	1785 MHz	33 dBm	0.53	29.8	36.5 dBm	-70.4	-69.0
	1910 MHz	33 dBm	0.54	31.7	36.0 dBm	-70.5	-72.4
DCS RX-ANT1	1880 MHz	0 dBm	0.65	-	-	-	-
PCS RX-ANT1	1990 MHz	0 dBm	0.67	-	-	-	-
WCDMA-ANT1	1980 MHz	26 dBm	0.57	30.3	36.2 dBm	-78.8	-89.5
	2170 MHz	0 dBm	0.62	-	-	-	-

a photograph of the antenna switch module. Figure 7 shows the transmission characteristics, and the measured result of this antenna switch module is summarized in Table II. Using a low insertion loss switch MMIC and a diplexer in LTCC allows production of a small antenna switch module.

V. Conclusion

We have developed the antenna switch MMIC for the GSM/DCS/PCS/WCDMA bands. This antenna switch MMIC achieves low insertion loss and small chip size with logic circuit using E/D mode p-HEMTs. The antenna switch MMIC is configured with the SPDT switch optimized for the GSM band and the SP4T switch for the other bands. The insertion loss is 0.21 dB at 915 MHz and 0.53 dB at 1785 MHz, and the isolation to the RX port is more than 30 dB. The input power at 0.1 dB compression is over 36 dBm at +2.7 V. The antenna switch module is demonstrated by using a diplexer in LTCC.

Acknowledgement

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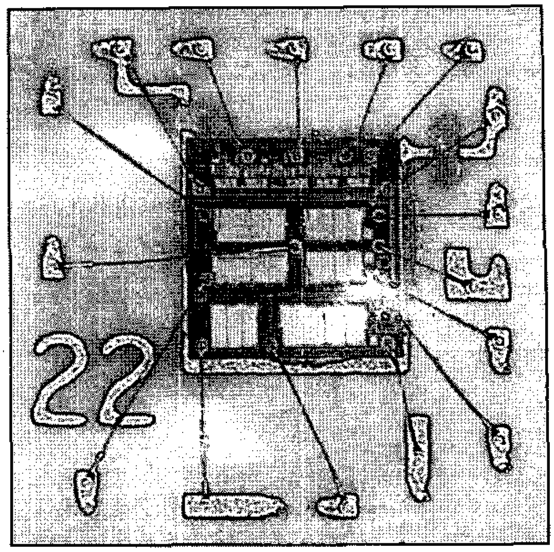

Fig.6. Photograph of Antenna Switch Module (LTCC: 3.8x3.8mm)

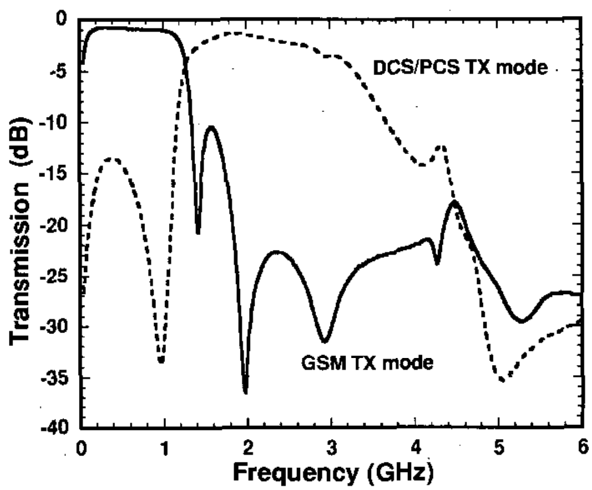

Fig.7. Transmission Characteristics of Antenna Switch Module

TABLE II Summary of Antenna Switch Module Characteristics

Pass	Condition		Loss (dB)	Harmonics Suppression (dB)		Harmonics Generation (dBc)	
	Frequency	Pin		$2f_0$	$3f_0$	$2f_0$	$3f_0$
GSM TX-Antenna	915 MHz	35 dBm	0.80	15.6	26.0	-80.8	-101.8
GSM RX-Antenna	960 MHz	0 dBm	0.95	-	-	-	-
DCS/PCS TX-Antenna	1785 MHz	33 dBm	1.14	6.5	34.8	-76.7	-92.0
	1910 MHz	33 dBm	1.11	6.5	30.5	-77.8	-84.8
DCS RX-Antenna	1880 MHz	0 dBm	1.15	-	-	-	-
PCS RX-Antenna	1990 MHz	0 dBm	1.10	-	-	-	-
WCDMA-Antenna	1980 MHz	26 dBm	1.09	11.3	18.4	-95.5	-90.5
	2170 MHz	0 dBm	1.17	-	-	-	-