# GaAs Switch ICs for Cellular Phone Antenna Impedance Matching

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**Abstract**

Recently cellular phones have been advancing toward multi-band and multi-mode phones and many of them are now provided with Near Field Communication (NFC) functions as represented by FeliCa. Their antennas are required to be capable of fine impedance matching so that the functions can be implemented in small cellular phones. The GaAs switch IC is suitable for such a purpose because of its low insertion loss, etc. This paper is intended to introduce the technologies and products of the GaAs switch ICs that have been developed by NEC Electronics for use in antenna impedance matching.

**Keywords**

cellular phone, antenna, multi-band, multi-mode, FeliCa, Near Field Communication (NFC)
GaAs, switch IC, insertion loss

## 1. Introduction

A mobile terminal with wireless communication functions such as the cellular phone is increasing the scale of the operating frequency bands and the modes of the systems incorporated in it. In particular, multi-band, multi-mode cellular phones and smart phones that can handle both GSM and UMTS (W-CDMA) are disseminated widely and they now incorporate various wireless communication systems such as Bluetooth, WLAN and a payment function based on Near Field Communication (NFC) as represented by FeliCa as well as the GPS and One-Seg systems.

In the past, most of the cellular phone used high-frequency switch ICs that switch high-frequency signals with low loss, high speed and low power consumption. However, recently, there is a demand for a switch IC that switches the antenna impedance in order to improve the antenna characteristics with the aim of exploiting more functions and higher performances from small antennas. In general, an antenna performs impedance matching with whatever frequency is in use in order to transmit signals with high power efficiency or to improve the receiving sensitivity. To obtain satisfactory characteristics over multiple frequencies or over a wide bandwidth, it is necessary to use an antenna sufficiently large for the wavelength or several antennas to be used according to the frequency in use. On the other hand, as a cellular phone is being reduced in size, it should incorporate only one small and compact antenna. However, the reduction in size of the antenna tends to deteriorate its characteristics and narrow the bandwidth. To use such an antenna in a multi-band operation (making it usable with two frequencies of 1GHz and 2GHz, for example), it is required to match the antenna impedance with the frequency used by means of a switch IC, etc.

On the other hand, FeliCa uses a coil antenna for the low frequency of 13.56MHz, and it is required to manifest stable communication characteristics even in the unstable one-touch operating condition. When a FeliCa antenna is mounted on a cellular phone, it is sometimes impossible to obtain satisfactory communication characteristics because of the fine deviation of the resonance frequency due to extraneous effects or variance in the assembly. This problem has been solved by switching and fine-adjusting the impedance matching elements for the antenna, such as the capacitors, using a switch IC.

Below, we describe the switch IC technologies and products developed for use in impedance adjustments of the compact built-in antenna and the FeliCa antenna that are for use in the GSM + UMTS multi-band, multi-mode cellular phones.

## 2. High–Frequency Switch IC and GaAs Switch IC Technologies

The multi-band, multi-mode cellular phones use an antenna switch IC that switches the paths of multiple high-frequen-

cy signals for the antenna. This function has previously been achieved by combining several PIN diodes, but this design needed a quarter-wavelength strip line and is not suitable for size reduction or composite configuration, so the recent trend is to apply the GaAs switch IC with its small size and low current drain. There is also a switch IC fabricated with a CMOS process of Si, but the high-frequency characteristics of GaAs have a superior performance, presenting for example a much lower signal loss when a signal passes through a selected circuit path. For the antenna impedance adjustment application that is the focus of this paper, what are required particularly are low loss characteristics and a capability of handling high passing signal power as well as an absence of passing signal distortion (low distortion characteristic). The costs of GaAs devices have previously been regarded as being high, but they have become relatively low thanks to the effects of mass-production. This has expanded the applications of GaAs to cover a much wider field than hitherto and inquiries from the fields that previously avoided GaAs because of the cost considerations are now increasing.

At NEC Electronics, we have adopted our originally-developed Heterojunction Field Effect Transistor (HJFET) to the switch IC [1)] . The active part of the HJFET consists of an undoped InGaAs channel layer sandwiched between an upper Si-doped AlGaAs layer and a lower Si-doped AlGaAs layer. The device has low on-resistance, high current density, excellent breakdown voltage and excellent current linearity. By applying the HJFET to the switch IC, we have been able to obtain low loss, low distortion and freedom from the mixing of signals (crosstalk) between different paths (good isolation characteristics) from a small switch IC chip.

In parallel with chip size reduction, we have also developed a compact package by developing and applying a thin, fine lead frame and gold-wire bonding of low height. As a result of these improvements, we have succeeded in commercializing switch IC products in a package size that is in the industry's smallest class.

## 3. Switch IC Products for Antenna Impedance Matching

Since the property required most of the antenna impedance matching is to match the impedance of large-amplitude signals with each antenna without loss, the GaAs switch IC is most suitable for this purpose as discussed above. In addition, in order to finish the products more attractively, we have accommodated the developed small chip in a compact, low-height package.

**Table 1** shows the representative characteristics of "µPG2183T6C," which is one of our antenna impedance matching switch IC products for multi-band, multi-mode cellular phones. As this application uses both GSM and UMTS in both of the 1GHz and 2GHz frequency bands, it is required to match a single compact antenna to the two frequency bands. The developed switch IC product utilizes the HJFET technology to switch the signal with a high 37.5dBm RF power from a single port to four ports (Single Pole 4 Throw: SP4T) with low losses of 0.4dB at 1GHz and 0.55dB at 2GHz.

The µPG2183T6C can also be used as the antenna switch for GSM, but if it is used in antenna impedance matching, it can switch the tuning elements to four impedance matching conditions as shown in **Fig. 1** . Its loss is lower than the switch IC fabricated using the Si device process, so it can contribute to transmission with high power efficiency and to reception with improved sensitivity. Its external view is shown in **Photo 1** . The port switching operation is controlled by a logic signal, and the product including this function is accommodated in a package with the dimensions of 3.0mm × 3.0mm × 0.75mm thickness.

The other product is an SP3T switch IC "µPG2404T6Q." This switch IC has the characteristics that allow it to be used also as the main antenna switch for CDMA. It also features significant size and thickness reduction from the previous impedance matching switch IC products used with the FeliCa antenna. Specifically, it maintains the equivalent characteristics to our existing SP3T product "µPG2031TQ" that has already been proven with CDMA and FeliCa antennas but it also features a reduced package size at the industry's most compact size of 2.0mm × 1.35mm × 0.4mm thickness. The size reduction is as significant as by 54% in mounting area and by 34% in thickness compared to our previous product. **Photo 2** shows the external view of the µPG2404T6Q.

**Table 2** shows the representative characteristics of the "µPG2404T6Q," which is a 3-control type SP3T switch IC operated by control voltages of 2.8V and 0V. With an insertion loss of 0.55dB, isolation of 21dB and power characteristic of +33dBm (P0.1dB) under the characteristic impedance condition of 50Ω in the 2GHz band. It has adequate characteristics for use as a main antenna switch for CDMA.

On the other hand, when it is used in impedance matching for the FeliCa antenna, it cannot achieve the same characteristics as are detailed above because the impedance condition is not always 50Ω and the frequency is much lower than the 2GHz

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Table 1 Electrical characteristics of μPG2183T6C.

| Parameter | Test Conditions | MIN. | TYP. | MAX. | Unit |
|---|---|---|---|---|---|
| Insertion Loss | f = 0.5 to 1.0GHz | – | 0.4 | 0.55 | dB |
| | f = 1.0 to 2.0GHz | – | 0.55 | 0.8 | dB |
| | f = 2.0 to 2.5GHz | – | 0.7 | 0.95 | dB |
| Isolation | f = 0.5 to 1.0GHz | 22 | 24 | – | dB |
| | f = 1.0 to 2.0GHz | 17 | 19 | – | dB |
| | f = 2.0 to 2.5GHz | 15 | 17 | – | dB |
| Input Return Loss | f = 0.5 to 2.5GHz | 15 | 19 | – | dB |
| Output Return Loss | f = 0.5 to 2.5GHz | 15 | 19 | – | dB |
| 0.1dB Loss Compression Input Power | f = 0.9GHz | +37.0 | +37.5 | – | dBm |
| | f = 1.8GHz | +34.0 | +35.0 | – | dBm |
| Harmonics | f = 0.9GHz, $P_{in}$= +34.5dBm | | −75 | −65 | dBc |
| | | | −75 | −65 | dBc |
| | f = 1.8GHz, $P_{in}$= +31.5dBm | | −72 | −62 | dBc |
| | | | −75 | −62 | dBc |
| Battery Current | Active mode, No RF | – | 0.55 | 1.5 | mA |
| | Stand by mode , No RF | – | – | 10 | uA |
| Switched Supply Current | $V_{DD}$ : High or Low , No RF | – | 0 | 0.1 | mA |
| Control Current | Vcont: High or Low , No RF | −100 | 0 | 100 | uA |
| Switch Control Speed | 50% CTL to 90/10 | – | 0.5 | 5.0 | us |
| Start Up Time | Time for the switch to be operational from that the switched supply voltage (Vdd) goes high. | | | 100 | us |

($T_A$ = +25°C, $V_{bat}$ = 3.0V, $V_{DD}$ = 2.65V, $V_{cont(H)}$ = 2.65V, $V_{cont(L)}$ = 0V, $Z_0$ = 50Ω, DC blocking capacitors = 56pF, Unless otherwise specified)

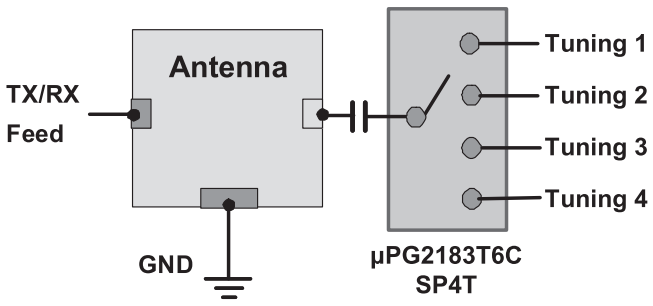


Fig. 1 Antenna impedance matching using μPG2183T6C.

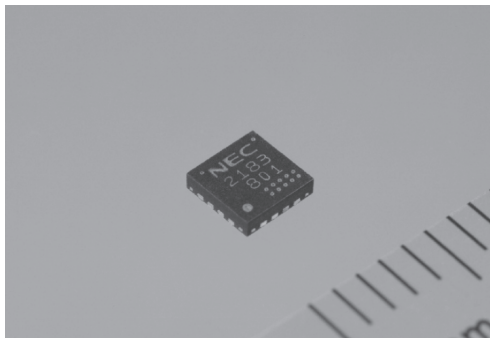

Photo 1 External view of μPG2183T6C.

band. However, the GaAs switch IC developed for use at high frequencies is still suitable thanks to its high breakdown voltage that is compatible with large voltage amplitudes input from the FeliCa antenna and to the low parasitic capacitance between the OFF port and GND of the switch IC that is important in switching very low capacitances. **Fig. 2** shows an example of application of the switch IC to impedance matching for a FeliCa antenna.

The SP3T circuit is connected in parallel with the FeliCa

Table 2 Electrical characteristics of the µPG2404T6Q.

| Parameter | Test Conditions | MIN. | TYP. | MAX. | Unit |
|---|---|---|---|---|---|
| Insertion Loss | f = 0.5 to 1.0GHz | – | 0.45 | 0.65 | dB |
| | f = 1.0 to 2.0GHz | – | 0.55 | 0.80 | dB |
| Isolation | f = 0.5 to 1.0GHz | 22 | 26 | – | dB |
| | f = 1.0 to 2.0GHz | 17 | 21 | – | dB |
| Input Return Loss | f = 0.5 to 2.0GHz | 15 | 20 | – | dB |
| Output Return Loss | f = 0.5 to 2.0GHz | 15 | 20 | – | dB |
| 0.1dB Loss Compression Input Power | f = 1.0GHz | +31.0 | +33.0 | – | dBm |
| 2nd Harmonics | f = 1.0GHz, $P_{in}$= 27dBm | 65 | 75 | – | dBc |
| 3rd Harmonics | f = 1.0GHz, $P_{in}$= 27dBm | 65 | 75 | – | dBc |
| Switch Control Current | RF None | – | 1 | 50 | µA |
| Switch Control Speed | | – | 150 | 5.0 | ns |

(TA = +25°C, Vcont (H) = 2.8 V, Vcont (L) = 0 V, ZO = 50 Ω,
DC blocking capacitors = 56 pF, unless otherwise specified)

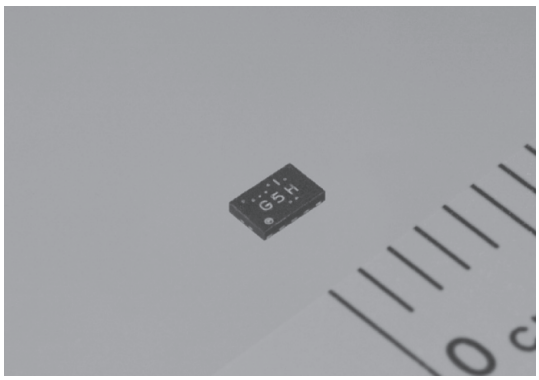

Photo 2 External view of the µPG2404T6Q.

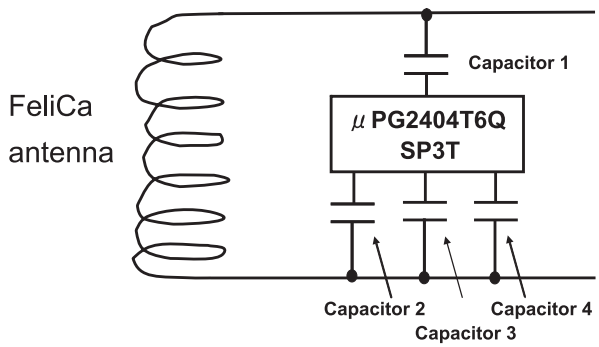


Fig. 2 FeliCa antenna impedance matching using µPG2404T6Q.

antenna and desired capacitors are connected to its input and three output ports. The capacitance value of the circuit is switched with logic signal controls to adjust the characteristics of the FeliCa antenna. The µPG2404T6Q has three control terminals and only the ports to which the high logic signal is applied are turned ON. Consequently, two or three ports of the SWIC can be turned simultaneously ON by turning two or three control signals simultaneously ON. This means that the combination of three capacitance values can create up to seven capacitance variations including simultaneous ON status. The use of the simultaneous ON status differs from ordinary switch ICs and is appropriate to the FeliCa antenna.

## 4. Future Perspectives, Conclusion

The recent trend of increasing the functions of cellular phones has led to a need for enhancements in the process of switching multiple RF signals and for impedance matching according to antennas in use. We are meeting this trend by developing ultracompact switch ICs equipped with increasingly complicated switching functions as well as by offering improved ease of use.

For the deployment of more compact package products, we are enhancing the line of multi-port switch ICs from SPDT to SP3T, SP4T and DPDT products. In order to contribute to further size and thickness reductions of wireless communication

equipment we intend to offer products that meet customers' needs in a timely manner.

*FeliCa is a registered trademark of Sony Corporation.

*The Bluetooth word mark and logo are properties of Bluetooth SIG, Inc., and NEC utilizes them under license.

## Reference

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