A High-Performance and Miniaturized Dual-Use (Antenna/Local) GaAs SPDT Switch IC Operating at +3V/0V

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Abstract

We have developed an ultra-compact dual-use (antenna/local) switch IC for PHS operating at +3/0 V. This IC has a circuit configuration which utilizes MESFETs with two kinds of pinch-off voltages. Additional applied techniques include a circuit design method that employed electromagnetic field analysis, a pull-up method which utilizes forward current flowing in order through the gates of MESFETs, and high isolation characteristic obtained by use of a chip inductor. The insertion loss and isolation characteristics of this IC are, respectively, 0.54 dB and 28.4 dB at 1.9 GHz and 0.48 dB and 30.0 dB at 1.65 GHz. Furthermore, we were able to suppress adjacent channel leakage power to 61.5 dBc at 600-kHz offset during input power of 22 dBm QPSK modulated signals.

Introduction

The PHS (Personal Handy phone System) service commenced operation in Japan from July 1995. The wireless access method used by this system is a TDMA (Time Division Multiple Access), and the transmission method is a TDD(Time Division Duplex)[1].

Figure 1 shows the TDMA/TDD frame timing. Identically-numbered slots(for example #1T and #1R) have the same frequency, but differently-numbered slots utilize slightly different frequencies. Because of this, the master unit which is used to communicate with multiple handsets must be able to switch between the difference frequencies for each slot within the guard bits that is positioned at the end of the slots. In actual system, a dual synthesizer configuration such as that shown in Figure 2 is used to carry out that high-speed switching operation. In this system, one synthesizer outputs a signal through one slot, while the other synthesizer completes the frequency changing operation. The two synthesizers alternate these operations, and the switching of the synthesizers is performed by switch ICs. With such a configuration, it is possible to carry out what appears to be instantaneous frequency switching. These switch ICs are known local switch ICs, and such switch ICs require high isolation characteristics in order to prevent interference and mixing of two respective frequencies.

Furthermore, use of the TDD method to switch between transmitting and receiving is carried out by an antenna switch IC, rather than by a duplexer which generally utilizes frequency selectability. This antenna switch IC needs to have low insertion losses in order to avoid transmis-

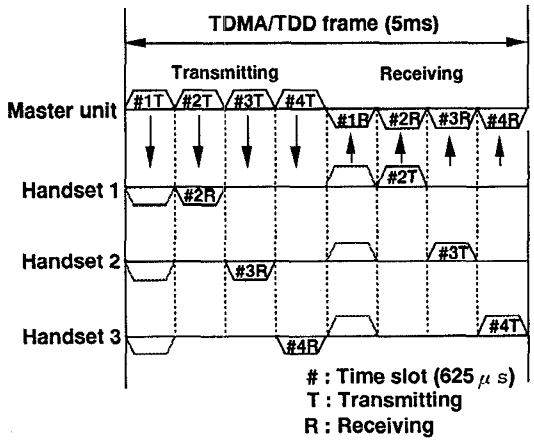

Figure 1 TDMA/TDD frame timing

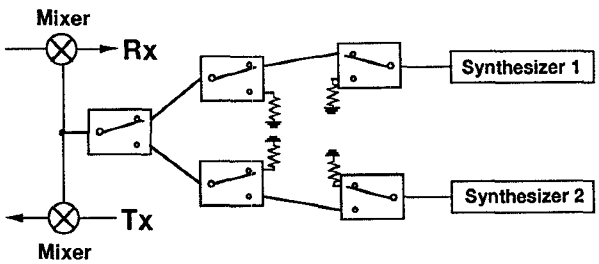

Figure 2 Dual synthesizer configuration

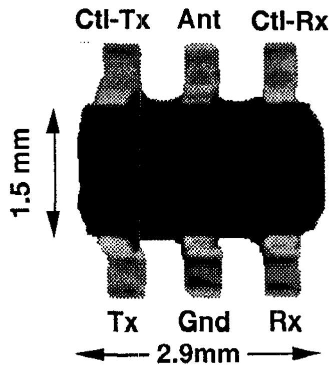

Figure 3 Package outline of CP6

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sion power losses during transmitting and to reduce noise during receiving. And also, because PHS utilizes a π /4 shift QPSK as the modulation method, a high degree of linearity in the input and output power transfer characteristic is required during the transmitting of signals [2].

Until now, we have been developing the following techniques in order to overcome the tradeoffs in performance of these switch ICs. A. Low control voltage/low distortion transmission technique: By using MESFETs with two kinds of pinch-off voltages (Vp), we were able to achieve low voltage operation and low levels of transmission distortion. This technique enabled us to develop antenna switch ICs for 0/-3 V and +3/0 V operation [3]. B. Compact/high isolation technique: By using electromagnetic field simulations, we were able to develop a local switch IC with isolation characteristics of 30 dB using a ultra-compact plastic package (called CP6: Chip Pack 6) which was 1/4th the size of conventional 8-pin package(SO8).

As the next stage in these techniques, we considered combining the two ICs onto one in order to reduce the number of parts and to achieve a reduction in cost. However, it is difficult to obtain high isolation characteristics of 30 dB when the antenna switch IC is sealed into the CP6. In order to solve this problem, we mounted a chip inductor between the Rx and Tx lead pins of the switch IC. The adoption of this new techniques made it possible to provide a high degree of isolation with almost no increase in the total mounting area, and furthermore with no deterioration in the insertion loss. By adding a chip inductor to an ultra-compact antenna switch operating at +3/0 V, the resulting IC could then be used as a dual-use switch IC (antenna/local) operating at +3/0 V.

The target specifications of this switch are shown below.

- A +3/0 V control voltage
- Antenna application (1.9 GHz) : Insertion loss ≦ 0.8 dB
  : Adjacent channel power ≧ 60 dBc (at input power of 22 dBm)
- Local application (1.65 GHz) : Isolation ≧ 30 dB
- Use of CP6

Design

The following section describes the techniques used in the development of the dual-use switch IC and the effects achieved.

A. Low voltage / low distortion transmission technique

The antenna switch IC for PHS applications needs to be able to transmit at 22 dBm power with little distortion. When receiving, however, the power level of signals is very low because of propagation through the air. In the case of the local application, this transmission power can be as low as 0 dBm. In other words, it is only necessary to transmit at relatively high power levels when the IC is being used as an antenna switch IC of transmitting operation. With this in mind, we adopted a circuit configuration that incorporates MESFETs with two kinds of Vp. Figure 4 shows the circuit configuration of this dual-use switch IC. The dotted line represents the package itself. L1 ~ L4 are the inductance component of the bonding wire and the lead pin of the package. In this

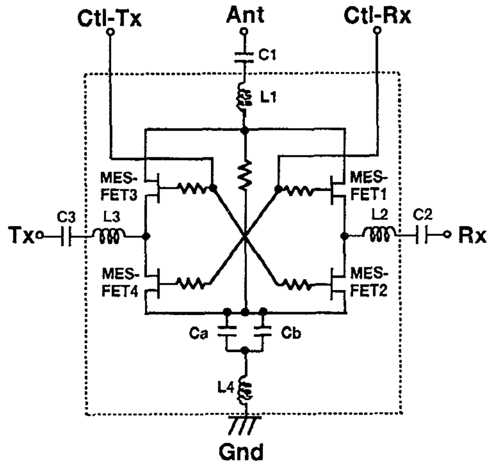

Figure 4 Circuit configuration of SPDT switch IC operating at +3/0 V

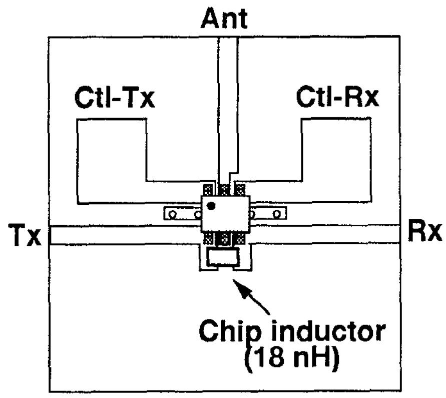

Figure 5 IC mounted with a chip inductor

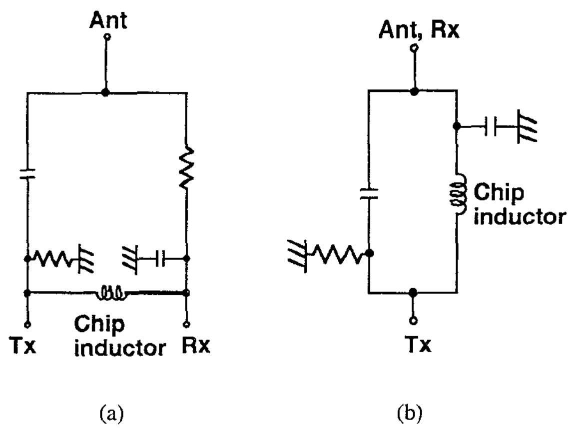

Figure 6 Simple equivalent circuit with a chip inductor
(a) Simple equivalent circuit (b) Transformed circuit of (a)

figure, MESFET1 and MESFET4 have a shallow Vp (Vp = -0.8 V), and MESFET2 and MESFET3 have a deep Vp (Vp = -2.4 V). This is because MESFET1 and MESFET4 need to keep OFF condition during transmitting operation, whereas MESFET2 and MESFET3 must have enough capacity to handle comparatively large current flows. Adoption of this technique makes it possible to achieve low distortion transmission at low control voltages.

B. Compact / high isolation technique

The use of a compact plastic package makes it extremely important to be able to evaluate the isolation characteristics of the package during signal propagation and to predict the characteristic deterioration that results from the plastic molding, and also to be able to determine the layout design rules that will yield the smallest possible IC chip size. Electromagnetic field simulation was used in order to realize these objectives. In order words, circuit simulation was carried out on the basis of a deterioration in isolation characteristics of 5 dB resulting from the CP6 plastic molding. In addition, because the isolation between the Ant and Ctl terminals of the package was 22 dB, the chip layout design rules were formulated to ensure that the isolation value did not drop below this. As a result, a minimum spacing of 30 μ m between RF-DC line was used for the layout design, and 2 μ m thick polyimide film was used as insulation film of the multilayered interconnection.

C. Reduction in the number of package lead pins / +3/0 V operation

The fully-monolithic antenna switch IC operating at +3/0 V which we had developed before now required a power supply pull-up terminal to pull the overall electrical potential V_{DD}. In the circuit shown in Figure 4, the +3 V potential which is applied to the Ctl terminal causes forward current to flow in order through each of the gates of the circuit MESFETs, thus charging the internally-mounted capacitors Ca and Cb and the externally-mounted capacitors C1 - C3, and pulling the overall electric potential up to +3 V. This has eliminated the need for a power supply terminal and makes it feasible to construct a 6-pin IC package which utilizes only 6 lead pins (RF1 - 3, Ctl1 - 2 and GND).

D. Low insertion loss / high isolation

This relationship is widely acknowledged to be a trade-off situation. However, by utilizing resonance characteristics, it is possible to obtain high isolation characteristics while maintaining low insertion loss. Figure 5 demonstrates the case where a chip inductor is mounted between the Rx and Tx lead pins. Even with the addition of this chip inductor, there is almost no increase in the total mounting area. Figure 6 (a) shows a simplified equivalent circuit of this switch IC. Because the value of Ron in the series MESFET is small, it can be ignored. Thus the circuit can be transformed as shown in Figure 6 (b). It can be seen from this that the resonance between the Coff of the series MESFET and the chip inductor means that it is possible to insulate the Ant/Rx side from the Tx side. In order words, by adding a chip inductor to the antenna switch IC, high isolation characteristic can be achieved, and the IC thus can also be used as a local switch IC. This technique leads

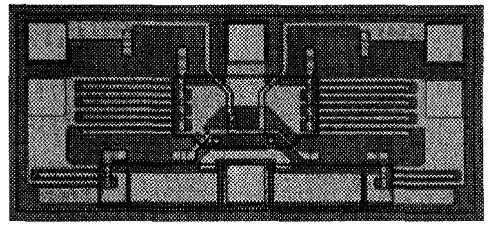

Figure 7 A chip photograph of the dual-use switch IC

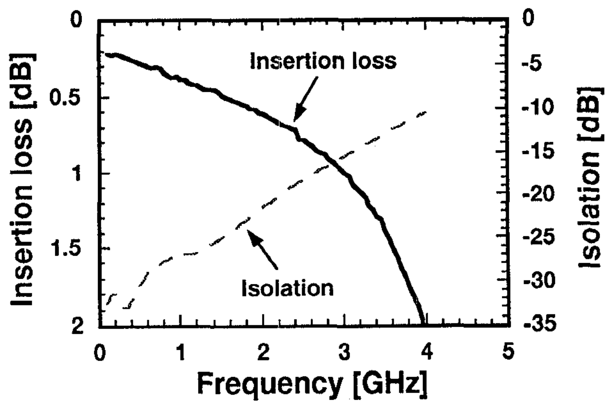

Figure 8 Measured insertion loss and isolation without a chip inductor

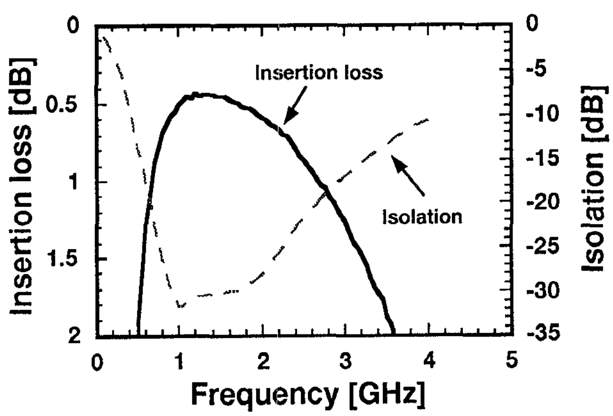

Figure 9 Measured insertion loss and isolation with a chip inductor

to conformity in switch ICs and also enables costs to be reduced.

Measured Results

Figure 7 shows a photograph of an IC chip that we have manufactured. The MESFETs used are planar-type MESFETs (with no recess) [5], and have gate lengths of 0.7 μ m. The gate widths are 1400 μ m for MESFET1 and MESFET3, and 400 μ m for MESFET2 and MESFET4. The pull-up capacitance is 10 pF (Ca + Cb), and the resistance applied to each gate is 7 k Ω . The chip size is a small 0.5 mm $\times$ 1.07 mm.

The insertion loss and isolation characteristics without a chip inductor are shown in Figure 8. The values are 0.55 dB for insertion loss and 23 dB for isolation at 1.9 GHz. The same properties with an 18 nH chip inductor added are shown in Figure 9. The resonance characteristics cause the frequency band to become narrower, but at 1.9 GHz, the values become 0.54 dB and 28.4 dB, while at 1.65 GHz they are 0.48 dB and 30.0 dB, respectively. Figure 10 shows the measurement results for adjacent channel leakage power. For 22 dBm input power, the characteristics reach 61.5 dBc at 600 kHz offset. The IC has output power at 1 dB gain compression point of 24.5 dBm.

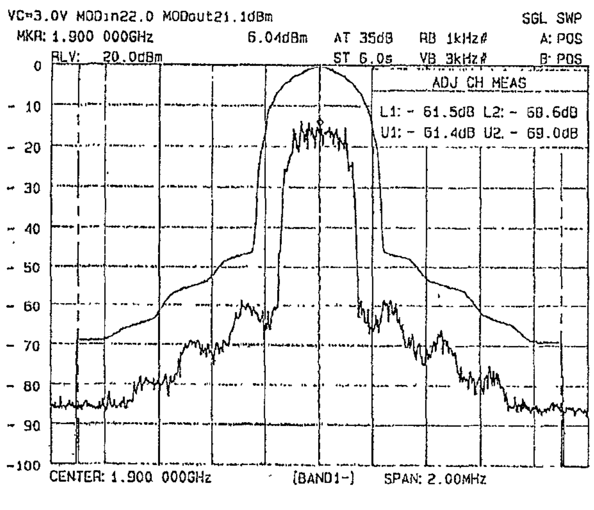

Figure 10 Output spectrum in QPSK operation

Conclusion

We developed a dual-use switch IC which utilizes an ultra-compact plastic package. When a chip inductor is not added, the switch IC can be used as an antenna switch IC; by adding a chip inductor, the switch IC can also be used as a local switch IC operating at +3/0 V.

Acknowledgment

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