ONBOARD LARGE-SCALE MONOLITHIC IC SWITCH MATRIX FOR MULTIBEAM COMMUNICATIONS SATELLITES†

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Abstract—For future high-capacity multibeam communications satellite services, a large-scale switch matrix, in which a large number of switch elements are incorporated, is necessary and the miniaturization of each element is required. Monolithic IC technology is useful for miniaturization of such a large-scale switch matrix. In this paper, newly developed switch matrix using monolithic GaAs IC technology has presented. As the switch matrix element, monolithic switch module which includes two $2 \times 2$ switch ICs and two driver ICs has been developed. A manufactured $16 \times 16$ switch matrix using the monolithic switch modules achieves high isolation greater than 40 dB and very fast switching time of $<50$ ns. Using monolithic switch modules, the switch matrix size has been reduced to about one-third that of the hybrid IC type without degradation of performances.

1. INTRODUCTION

A satellite-switched time division multiple access (SS-TDMA) system, employing a multibeam antenna, is a promising technological approach for high-capacity satellite communications [1, 2]. In this system, a switch matrix, which interconnects onboard receivers to transmitters, is a key device. Future high-capacity communications satellite services will require many spot beams. Japan’s future domestic communication satellite service is expected to utilize more than 10 beams [3]. Thus, a large-scale switch matrix, in which a large number of switch elements are incorporated, is necessary and the miniaturization of each element is also required. Monolithic IC technology is useful for miniaturization of such a large scale switch matrix.

In this paper, a newly developed switch matrix using monolithic IC technology is described, and switch matrix requirements and performance are discussed.

2. SWITCH MATRIX REQUIREMENTS

2.1. Operation mode

A block diagram of the SS-TDMA transponder is shown in Fig. 1. The interconnection between the onboard receivers (RXs) and transmitters (TXs) is achieved through the IF-band switch matrix (IF switch matrix). This is accomplished according to programmable switching patterns stored in the satellite switch controller (SSC). The interconnection pattern sequence data can be changed by a command from the terrestrial communication control center via a TT&C subsystem. In the SS-TDMA system, the required operation modes [4] for the IF switch matrix are as follows:

(a) Connect any input to any output regardless of what other connections may exist at the time.
(b) Connect any input to one or multiple outputs (distribution mode).
(c) Connect one or multiple inputs to any output (combining mode).

2.2. Required performance

In a high-capacity multibeam system, many onboard receivers and transmitters are used. The scale of the IF switch matrix requires $N \times N$ for $N$ receivers and $N$ transmitters. That is, the scale of the IF switch matrix is increased by $N^2$ times. In future multibeam systems [3], a matrix scale of $20 \times 20$–40 × 40 will be required for the IF switch matrix. In conventional hybrid IC technology, IF switch matrix weight exceeds several tens of kilograms. A weight reduction of at least one-half to two-thirds is required.

Required performance of the IF switch matrix presented here is as follows:

(a) High isolation exceeding 40 dB between input and output to reduce interference among signals.
(b) Very fast switching time of $<50$ ns to enhance utilization efficiency of the transponder.
(c) Wide signal bandwidth of 200 MHz to be applied to wide band signal transmission.
(d) 7-year survival probability $>0.9$.
(e) Durability to withstand satellite environmental conditions.

Isolation characteristics of circuits on an IC chip are degraded by electrical coupling. Further, the on-to-off ratio of an FET is decreased by the effect of parasitic capacitance, as frequency increases. Thus, signal frequency is selected at the 1 GHz-band.

2.3. Redundant system

To enhance IF switch matrix operational reliability, cross-point redundancy [5] is introduced into the IF switch matrix. This is because of the high reliability obtained with small size and simple configuration. In cross-point redundancy, each cross-point switch has two switches which back up each other and are controlled separately by the SSC [6].

3. MONOLITHIC GaAs SWITCH

3.1. 2 x 2 switch IC

Signal line cross-over can not be employed on the IC chip, because signal coupling between lines at the cross-over degrades isolation characteristics. Therefore, a 2 x 2 matrix switch is selected as the switch IC scale to avoid crossing lines on a chip. A GaAs FET was chosen as the switching element because of its high switching speed, high isolation and low driving power. Circuit configuration is shown in Fig. 2. Four SPST (single pole single throw) switches are arranged in one chip. Lumped-element circuitry is used to reduce IC size. The 2 x 2 switch IC is composed on a 2.7 x 3.9 mm² GaAs chip.

Reverse isolation (output/input isolation) independent of switch conditions and minimal change of input impedance between on-state and off-state are required for each SPST switch to operate in the distribution or combining modes. Therefore, a ground-source amplifier type switch is employed as the SPST switch. Each SPST switch in the 2 x 2 switch IC consists of a main switch and a buffer amplifier. To achieve high on-to-off ratio and high isolation characteristics, FETs for RF signals are separated from FETs for control signals. To reduce power consumption, current flowing through the main switch and through the buffer amplifier are simultaneously cut in the off-state SPST switch.

3.2. Driver IC

Driver circuits are required to convert control signals from the SSC into the switch IC drive bias level. To reduce IF switch matrix equipment size, four driver circuits are integrated into a 1.3 x 2.7 mm² GaAs chip (driver IC). The driver IC controls four SPST switches in the 2 x 2 switch IC.

3.3. Packaging

To minimize equipment size and to install cross-point redundancy, two switch IC chips and two driver IC chips are assembled in a hermetically sealed package (monolithic switch module). An external view of the monolithic switch module is shown in Fig. 3. Package dimensions are 21.5 x 30 x 5.8 mm³. If the switch IC and/or driver IC fails in the permanent “on” mode, the input signal is transmitted to the output port in spite of the “off” control signal. To escape from this failure, the drain bias fed to the switch IC can be cut off by a ground command.

Packaging is also important for determining isolation characteristics. An internal and external top view of the monolithic switch module are shown in
Fig. 4. Internal and external top view of the monolithic switch module.

Fig. 4. In the switch module package, ceramic multi-layered substrate tri-plate lines, which connect the monolithic IC chips to the package input/output pins, were employed to minimize electrical coupling between the lines and to reduce interference between signals.

3.4. Monolithic switch module performance

Measured on-to-off ratio vs frequency of the switch module is shown in Fig. 5. On-to-off ratio of > 60 dB is obtained over the required frequency band from 900 to 1100 MHz. Insertion gain is about 2 dB at 1 GHz. Switching time is < 10 ns.

4. IF SWITCH MATRIX

4.1. IF switch matrix configuration

Utilizing $M \times N$ switch modules, a $2M \times 2N$ IF switch matrix can be composed with cross-point redundancy. To inject IF signals into the switch modules, planar mechanical construction is desirable to insure high reliability. Thus, a coupler crossbar configuration [7] is employed as shown in Fig. 6.

Coupler crossbar architecture is accomplished in two layers to avoid crossing input and output signal transmission lines. Input signal transmission lines are set in the top layer and output signal transmission lines are set in the bottom layer. The input couplers within the top layer couple IF signal energy from the input line to the switch modules. Switch module output signals flow through the output couplers within the bottom layer to the selected output lines.

4.2. $16 \times 16$ IF switch matrix configuration and performance

A $16 \times 16$ IF switch matrix using monolithic switch modules has been manufactured. An external view of the IF switch matrix is shown in Fig. 7. The IF switch matrix housing is made of gold-plated magnesium alloy. Equipment dimensions are $270 \times 222 \times 130$ mm$^3$ with cross-point redundancy and one-out-of-two redundant d.c./d.c. converters. Seven-year survival probability is > 0.9. The $16 \times 16$ IF switch matrix consists of four $8 \times 8$ submatrix switches. An internal view of the $8 \times 8$ submatrix is shown in Fig. 8. The $8 \times 8$ submatrix switch consists of input dividers, 16 switch modules, output combiners and a decoder logic circuit. The decoder logic circuit is fabricated with a CMOS gate-array LSI to insure small size, low power consumption and high reliability. The LSI has radiation hardness performance.

A weight comparison between the $16 \times 16$ IF switch matrix using monolithic switch modules and one using hybrid ICs is shown in Fig. 9. Most of the total weight in the switch matrix is accounted for by switches and housing. Housing weight can be reduced by switch size reduction. Therefore, reducing switch size is effective for switch matrix miniaturization.
Fig. 7. External view of the $16 \times 16$ IF switch matrix.

Fig. 8. Internal view of the $8 \times 8$ submatrix.

Fig. 9. Weight comparison between the $16 \times 16$ IF switch matrix using the monolithic switch modules and one using hybrid ICs.

Fig. 10. Minimum on-to-off ratio of the $16 \times 16$ IF switch matrix.
5. CONCLUSION

A newly developed monolithic switch module which includes two $2 \times 2$ switch ICs and two driver ICs has been presented. The manufactured $16 \times 16$ IF switch matrix using monolithic switch modules achieves high isolation $>40$ dB and very fast switching time of $<50$ ns. It was also demonstrated that the size of this monolithic IF switch matrix is reduced to about one-third that of hybrid IC type. The monolithic switch matrix is attractive for future high-capacity multibeam communications satellites. To confirm performance of the monolithic IF switch matrix, onboard experiments are planned using the Japanese 2-ton class satellite, ETS-VI to be launched in 1992.

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