A 900MHz 90 DEGREES HYBRID FOR QPSK MODULATOR

Seiichi Arai, Akira Kato, Kazuaki Minami and Toshio Nishikawa

Murata Manufacturing Co., Ltd.
Nagaokakyo-shi, Kyoto 617 Japan

Abstract

A miniaturized surface mounting 90 degrees hybrid using a meandered thin film microstrip line directional coupler has been developed for the QPSK modulator. The coupling level of the narrow spacing parallel lines on a high dielectric constant (K) ceramics was calculated using Finite Element Method (FEM) and a circuit simulator. Balanced outputs and quadrature phase difference in the frequency range of 950 MHz ± 10 MHz were obtained experimentally at the size of 1.7 (H) x 4.8 (W) x 6.2 (D) mm.

Introduction

Recently it has determined to adopt $\pi/4$ shift QPSK modulation for digital cellular radio systems in Japan and U.S. and GMSK modulation for Pan-European cellular radio as Groupe Spécial Mobile (GSM). These digital cellular systems above are about to come out in a few years. Both QPSK modulation and GMSK modulation need QPSK modulators which consist of an in-phase power combiner, two BPSK modulators and a 90 degrees hybrid which has an equal output level and quadrature phase. The 90 degrees hybrid would be the key part for this modulation system, because the allowable phase error is very small (within 3 degrees at the output of the transmitter) and a 90 degrees hybrid in the modulator substantially determines the phase error of the transmitter.

We have newly developed a 90 degrees hybrid adopting a simple microstrip line directional coupler on a high K ceramic substrate using thin film technique. This hybrid has configuration of SMD (Surface Mount Devices), which meets current user's demand.

Configuration

A microstrip type coupled line seems to be a promising candidate for a 90 degrees hybrid, but it was said that microstrip type coupled lines had a difficulty to obtain tight coupling of 3 dB due to limitation of narrow line spacing in case that conductor thickness has an order of skin depth, estimated 2 to 3 μm at 900MHz.

However, since coupled microstrip lines have an advantage of simple planar configuration, it is much better in terms of low production cost than other configurations such as Lange coupler [1] which requires wire bonding or multi-layered configuration [2].

We put stress not upon insertion loss, but upon an equal output level and exact 90 degrees phase shift, because the increase of insertion loss of the hybrid can be compensated by an amplifier without S/N degradation in case of modulator application. In other words, at the expense of insertion loss, we adopted such thin conductor that shapes the narrow line spacing for tight coupling. The basic structure of the newly developed 90 degrees hybrid is shown schematically in Figure 1. It was fabricated on a high K ceramic substrate, which has a configuration of a quarter wavelength distributed coupled lines.

Coupler Design

In-house FEM simulator, based on two-dimensional Laplace equations, was applied to carry out even and odd mode impedance analysis of coupled lines. The element mesh employed in the cross section is shown in Figure 2. Boundary conditions for both modes are shown in Figure 3, where the solid lines show electric walls and the broken lines show magnetic walls. For open side boundary conditions, we took a finite region mapping [3]. Using FEM calculation above, characteristic impedances (Zoe, Zoo for each mode) and effective dielectric constants (Eeffe, Eeffo for each mode) were obtained. From these values and coupled line length, frequency characteristics of the coupler expressed in S-parameters were calculated using a linear microwave simulator (Touchstone). Such a two-step procedure was employed because a Touchstone-like simulator by itself does not guarantee a sufficient accuracy in case of entering very narrow line spacing and line width compared with the substrate height.

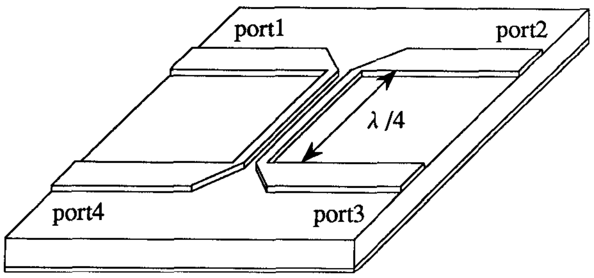


Fig.1 Schematic illustration of the 90 degrees hybrid

In the design of a 90 degrees hybrid, we chose the substrate material which has relative dielectric constant of 21 among various high K materials [4] to obtain short coupler length. Materials of higher K such as 39 or 90 were not employed because of too narrow line width to match to 50Ω. The characteristics of coupled lines were calculated under a number of different physical conditions of 25 to 100 μm in line width, 10 to 20 μm in line spacing and 0.8 to 1.2 mm in substrate height.

The broken curves in Figure 4 show the calculated line spacing versus line width plot using our FEM where the two outputs have equal levels for three kinds of substrate height. And dotted curve for 1.0mm thick substrate shows another calculated plot using rectangular boundary division method [5] for comparison. Figure 4 shows the coupling has weak dependency on line width and became tighter as the substrate goes thicker. Tight coupling can be achieved at the possible dimensions to realize using current technique of photolithography.

Figure 5 shows the calculated frequency characteristics of the coupler for one of the conditions (width: 100 μm, spacing: 20 μm, height: 1.2 mm, coupled line length: 20 mm). As shown in Figure 5(a), the calculated magnitude difference of S_{21} and S_{41} at center frequency is almost 0 dB. This means tight coupling is achievable using microstrip type of coupled lines.

Phase difference between S_{21} and S_{41} is shown in the Figure 5(b). The isolation between port 1 and port 3, and the return losses of an input (port 1) and output (port 2 and port 4), are shown in the Figure 5(c) and 5(d), respectively. The isolation and return loss are predicted better than 27dB.

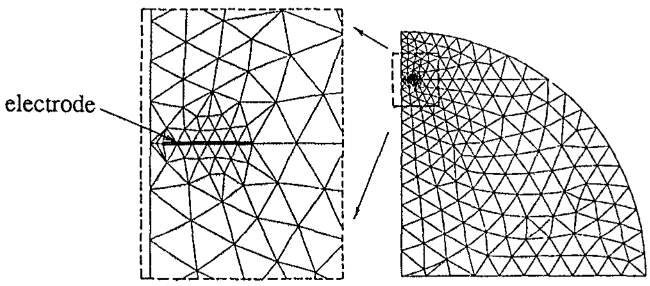


Fig.2 Mesh for FEM simulation in the coupler cross section

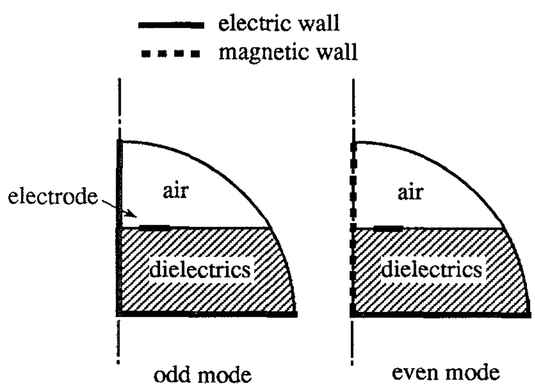


Fig.3 Boundary conditions in the coupler cross ssection

Experimental Results

As shown in Figure 6, the 90 degrees hybrids were fabricated on a polished ceramic substrate using thin film photolithography process. The dimensions of the hybrid were 25 mm x 5 mm x 1.2 mm. The ceramic substrate of $MgTiO_3$-$CaTiO_3$ system was used, which has Q value of 55,000 at 1GHz and temperature coefficient of dielectric constant of 0-6 ppm/degree C. Conductor metals, consisting of Nickel-Chromium layer (400Å) and Gold layer (2500Å), were thinner than usual to realize precise narrow gap. Input (port 1), output (port 2 and port 4) and isolation (port 3) terminals as a solder pad are formed on the side walls of the substrate. Back plane, except portions close to the terminals mentioned above, was metallized as a ground and connected to two of the side terminals.

Figure 5 shows a comparison between experimental results and calculation. In Figure 5(a), output level obtained experimentally was as low as 1 dB compared with calculated one and coupling level was a little lower than that of estimation. The excess loss is supposed to be ohmic loss of thin conductor as well as narrow line width. In Figure 4, the solid curves show the measured spacing versus width plot where the two outputs gave equal levels. Calculation did not predict precise dimensions of coupled line structure, but it provides the order of line spacing and line width.

Miniaturization

The 90 degrees hybrid should be as small as possible for portable cellular radio applications. To meet this requirement, it was modified to occupy smaller areas using meandered line technique, which is shown in Figure 7. And as a physical protection of the substrate surface, shown in Figure 8, the surface was covered with silicone rubber, maintaining SMD structure. The velocity factor of 0.75 may come from discontinuities at curved coupled lines. The length of the meandered lines are adjusted experimentally to have 90 degrees phase difference and an equal output level at desired frequency range, 950 MHz ± 10 MHz.After adjusting the coupled lines, we have reached favorable characteristics shown in Figure 9 and Table 1 which can be used as a part of QPSK modulator.

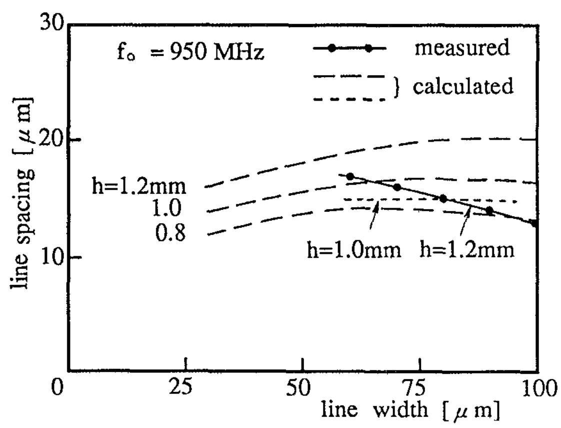
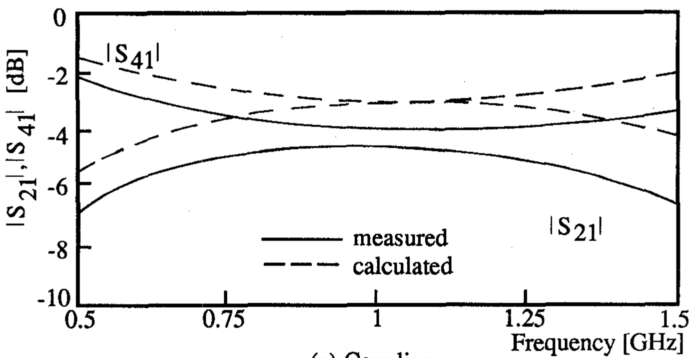
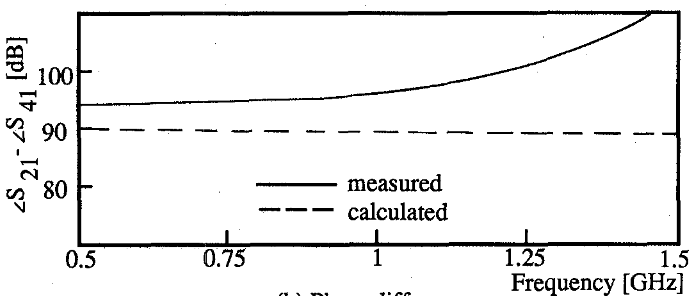


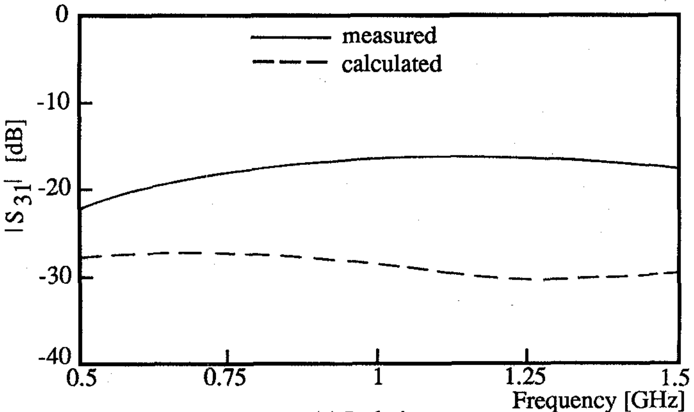
Fig.4 Spacing vs width plot where the two output levels are the same



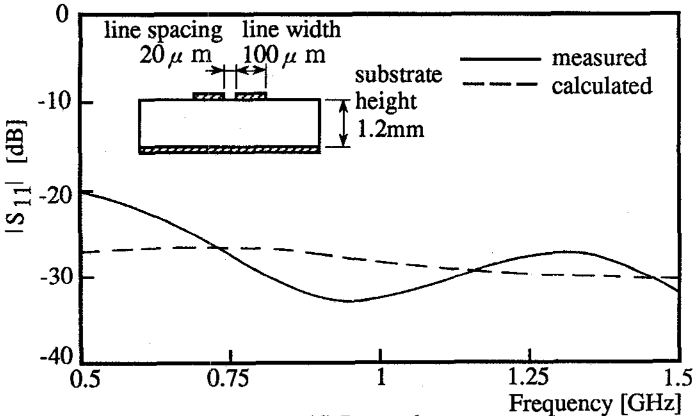
(a) Coupling



(b) Phase difference



(c) Isolation



(d) Return loss

Fig.5 Frequency characteristics of 90 degrees hybrid

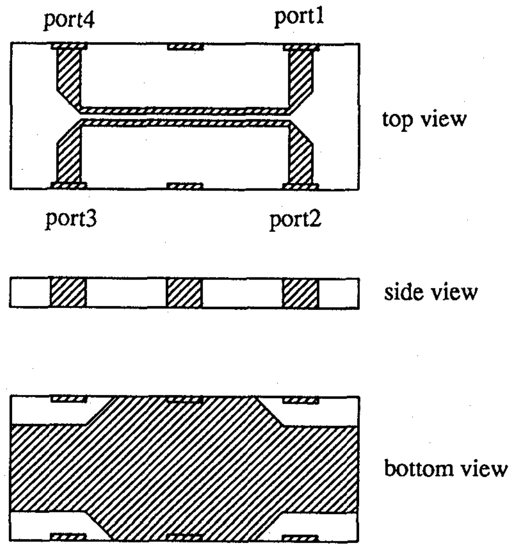


Fig.6 Schematic views of SMD type 90 degrees hybrid

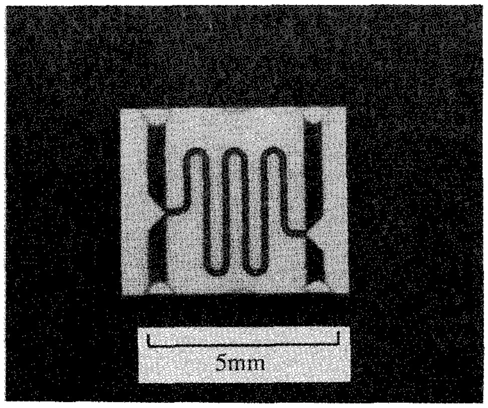


Fig.7 Photograph of the meandered coupled line

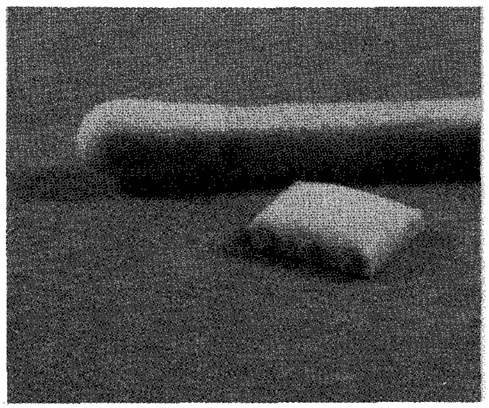


Fig.8 Photograph of the 90 degrees hybrid
The upper shows a matchstick and
the lower shows the hybrid

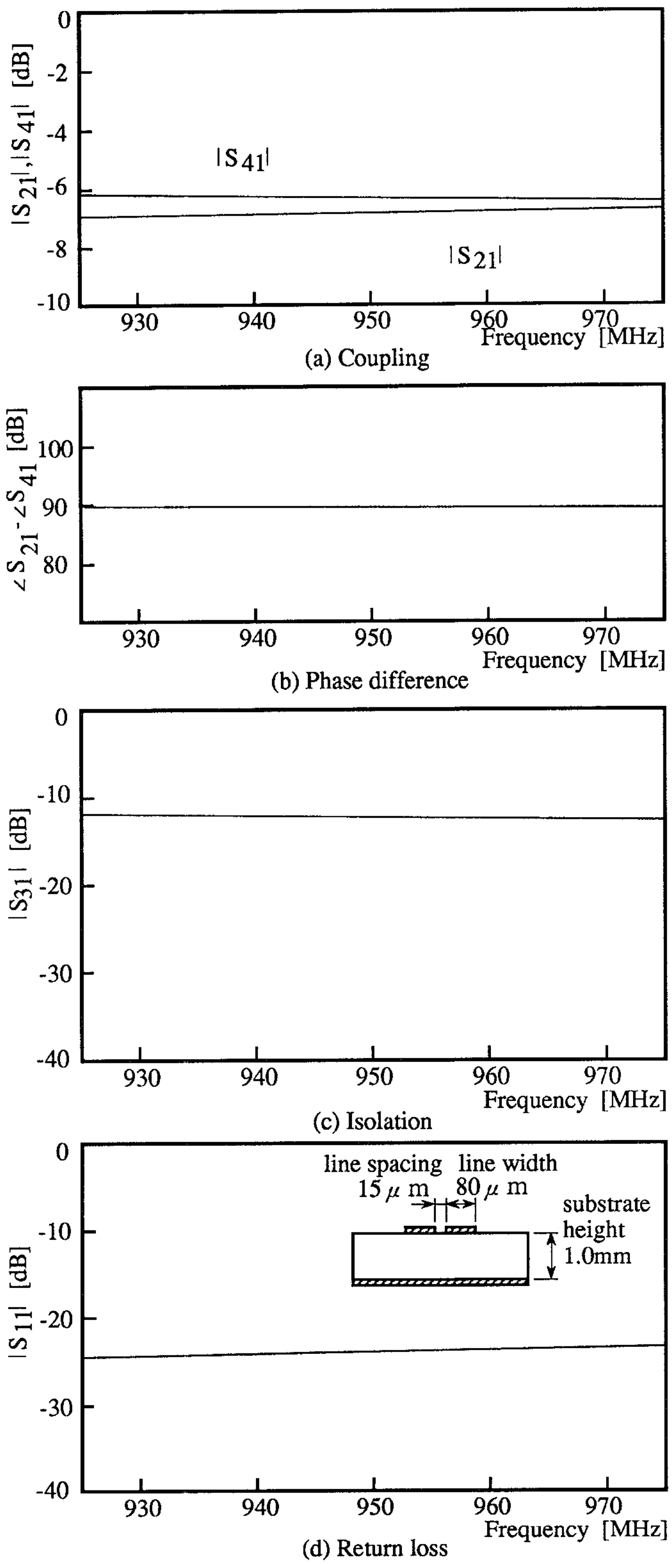


Fig.9 Typical performance of the minituarized 90 degrees hybrid

Table 1.
Typical characteristics of the miniatuarized 90 degrees hybrid at 950 ± 10MHz

Item	Typical Value
Amplitude Balance	0.4dB
Deviation from Quadrature	1.3degrees
Isolation	12.0dB
Insertion Loss	6.7dB (power split loss included)
VSWR	1.2
Dimensions	1.7(H)x4.8(W)x6.2(D) mm (Silicone rubber included)

Summary

The calculated and fabricated results on small surface mounting 90 degrees hybrid have been described. The hybrid consists of coupled microstrip lines on a high K ceramic substrate which has relative dielectric constant of 21 and thickness of 1.2 mm. Using both FEM and a circuit simulator, physical dimensions of the coupled line were determined where the output levels are balanced and phase difference is 90 degrees. One of the resulting dimensions was 100 μm in line width and 20 μm in line spacing. Though measured coupling are weaker than estimation, tight coupling was obtained near a predicted region. To meet the market demand, it was modified to smaller surface mounting devices using meander lines. Thus we obtained 90 ± 1.4 degrees phase shift and 0.4 dB level balance at final dimensions of 1.7 (H) x 4.8 (W) x 6.2 (D) mm.

Acknowledgment

The authors would like to thank Professor Eikichi Yamashita of the University of Electro-Communications for providing his calculated results using rectangular boundary division method shown in Figure 4. and helpful suggestions on our analysis, Dr. Kikuo Wakino for his support and encouragements.

References

[1] J.Lange: "Interdigitated Stripline Quadrature Hybrid",IEEE Trans. Microwave Theory Tech., MTT-17, pp.1150-1151 (Dec. 1969)

[2] M.Nakajima and E.Yamashita: "Quasi-TEM Wave Chracterization Method for Tightly Coupled Microstrip Lines with Conductor Overlay", Trans. IEICE, E73, No.6, pp.959-967 (June 1990)

[3] M.Matsuhara and M.Ishizaki: "Finite Element Method for Open Type Waveguide", Trans. IEICE, J73-C-I, No.11, pp741-743 (Nov. 1990)

[4] K.Wakino et al.: "Dielectric Materials for Dielectric Resonator", 1976 Joint Convension Record of Four Institute of Electrical Engineers, Japan No.235 (1976)

[5] E.Yamashita, M.Nakajima and K.Atsuki: "Analysis Method for Generalized Suspended Striplines", IEEE Trans. Microwave Theory Tech., MTT-34, pp1457-1463 (Dec.1986)