Suppression of Multi-path Couplings in MCM with a Flip-Chipped SiGe-MMIC

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Abstract — **Techniques to obtain high isolation property in a multi-chip module (MCM) between pads of a SiGe-MMIC flip-chipped on a low temperature co-fired ceramic (LTCC) are discussed. In such a MCM, there are two coupling paths. One is a path through the LTCC and the other is a path through the MMIC. To improve the total isolation property, structures to reduce the two coupling paths are required because the paths of such leaks are not in series but in parallel. We examined disposition of several kinds of ground patterns on the LTCC. Also, we devised a metal plate on a bias circuit as a shielding structure on the SiGe-MMIC. The effectiveness of the isolating structures was verified by measuring IIP2 in a receiver MCM with a direct conversion SiGe-MMIC. The IIP2 property has been improved successfully as well as the isolation property.**

I. Introduction

Reductions of cost and size of RF transceiver modules are strongly desired these days. For cost reduction, silicon MMICs have been adopted for higher frequency applications by using SiGe-process. For size reduction, MCMs with flip-chipped MMICs on a LTCC multi-layer package become widely used [1-3]. However, Si substrate has low isolation property because of its low resistivity. In addition, for a flip-chipped MMIC structure, there exists a LTCC above circuits of the MMIC as a dielectric material. This also causes undesired couplings among elements of MMIC circuits.

To improve isolation property, coupling through LTCC and that through MMIC must be diminished at the same time. As for improvement of isolation in MMIC, some techniques was already developed such as deep trenches that block current leakage at an epitaxial layer. D. Greenberg [4] devised the deep trenches with substrate contacts as isolating devices and introduced shielding structures of signal lines with the trenches. We introduced a metal plate on the bias circuit of MMIC and connected it to Si substrate and ground pads. We examined the property by electromagnetic (EM) simulation. Also, we calculated the property in the cases that the plate connected to the pad that connected to absolute ground through inductive vias.

Next, we disposed several kinds of ground patterns on LTCC. Small ground patterns were disposed beside or underneath of lines. Also, a small metal plate were disposed on the LTCC just underneath bias circuits of the flip-chipped MMIC. The properties of isolation for each pattern are calculated by EM simulation.

The isolation properties of the ground patterns on LTCC and the shielding structures in MMIC was evaluated separately, but total property is not the sum of them because the paths of leaks are not in series but in parallel.

The effectiveness of the proposed isolating structures was verified by measurements of IIP2 in a receiver MCM with a direct conversion SiGe-MMIC. The mechanism of decrease of IIP2 due to those unexpected couplings of a local signal to an LNA is explained in section III. The results shows that the techniques works well and is indispensable for development of small MCMs for mobile phones.

II. Couplings in MCM

A. Multi-path coupling in MCM

Fig. 1 shows a typical MCM structure with a flip-chipped MMIC. Unexpected coupling paths are in both MMIC and LTCC.

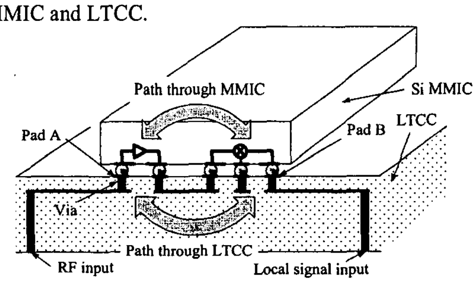

Figure 1: Typical MCM structure

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A signal traces a line in the LTCC through vias and internal components, then reaches to pad A on the surface. Through a small solder ball, the signal goes into the MMIC and returns to the LTCC again. Passing other components, the signal comes back into the MMIC and goes out to the LTCC again. In the meanwhile, two kinds of unexpected coupling paths might exist in the MCM. One is the path through the MMIC and the other is the path through the LTCC.

If the isolation properties between the pad A and the pad B are S_{LTCC} [dB] in LTCC and S_{MMIC} [dB] in MMIC, the total isolation property becomes

$$20\log(10^{\frac{-S_{LTCC}}{20}}+10^{\frac{-S_{MMIC}}{20}}) \quad (1)$$

in dB. This shows reducing coupling of one of the paths is not enough to improve the total isolation property.

B. Shielding structures in Si MMIC

Fig.2 shows shielding structures in MMIC. In this case, deep trenches combined with metal lines and substrate contacts are placed between amplifier circuits and bias circuits, and also placed between mixer circuits and bias circuits.

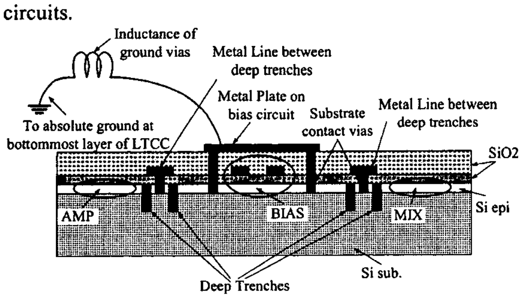

Figure 2: Shielding structures in MMIC

Our proposing metal plate is disposed above the bias circuit. The plate is connected to Si substrate by substrate-contact vias. Also the plate is connected to ground pads of MMIC.

The isolation properties are calculated by EM simulation (HFSS by Ansoft). Ports of simulation are set at the amplifier's portion and the mixer's portion of Fig.2. Two-port S parameters are recalculated to the maximum available gain (MAG) to obtain the properties for matched-port conditions. Table 1 shows the isolation properties with changing the number of trenches. The results show deep trenches improve only 2 dB isolation of EM couplings.

Table 2 shows the property with/without the shielding metal plate and that with several inductance between a ground pad of MMIC and the absolute ground.

Table 1: EM isolation properties of the deep trenches with metal line at 1 GHz

Number of trenches	Isolation (MAG [dB])
0	21.6
1	21.9
2	22.8
3	22.9
2 Metal line w/ sub. con.	23.5

Table 2: EM isolation properties of the metal plate at 1GHz

Inductance to GND	Isolation (MAG [dB])
without metal plate	22.8
0 nH	37.8
0.5 nH	37.1
1.0 nH	36.4
1.5 nH	35.8

Compared to trenches, the shielding metal plate improves isolation property very much. If we introduce all shielding structures and we assume the inductance of via connecting ground pad to absolute ground is 0.5 nH, the isolation property would improve 14.3 dB.

C. Decoupling ground patterns on LTCC

The schematic diagram of devised ground patterns on a LTCC with a flip-chipped MMIC is shown in Fig.3. The isolation properties of some kinds of ground patterns are calculated by EM simulation (EMsight by AWR). Fig. 4 shows four models of calculations. (a) has no ground patters, (b) has several ground patterns beside lines, (c) has ground patterns underneath the lines and (d) has ground plate just underneath the bias circuit of MMIC as well as the ground patterns of (c).

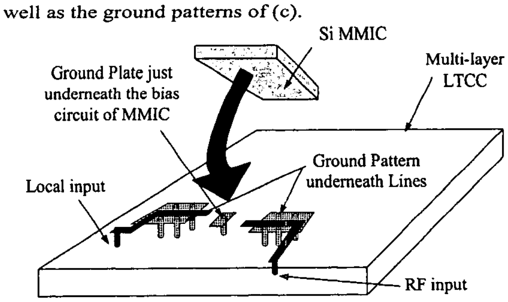

Figure 3: MCM with flip-chipped MMIC

Ground patterns under lines improve isolation by about 30 dB form the case of just two lines and 20 dB from the case of ground patterns beside lines at 1 GHz. Ground plate under the MMIC improves the isolation by 10 dB more than (c) at 1 GHz in this case.

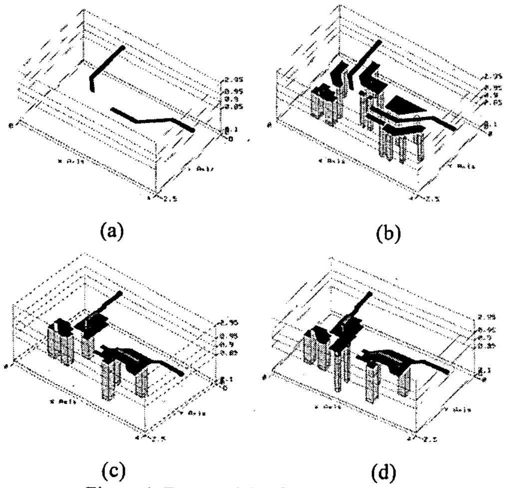

Figure 4: Four models of ground patterns

The calculated results are shown in Fig.5.

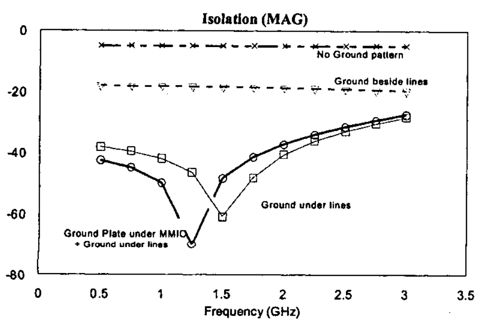

Figure 5: Isolation properties of ground patterns

Table 3 shows measured results of (c) and (d) with/without MMIC. (d) improved isolation by 11.5 dB, which agrees well with the calculated result.

From this result, the isolation of the MMIC can be calculated as follows.

$$-20\log(10^{\frac{-27.4}{20}} - 10^{\frac{-30.7}{20}}) = 37.4 \qquad (3)$$

The isolation levels of LTCC and MMIC are almost the same, so we need to reduce both couplings of them. If the MMIC improves the isolation by 14.3 dB and if the LTCC improves it by more than 30 dB, then total isolation, which would be dominated by MMIC coupling, become about 50 dB.

Table 3: Measured isolation with ground patterns (c) and (d), with/without MMIC at 1GHz

patterns and MMIC	Isolation (MAG [dB])
(c) without MMIC	30.7
(c) with MMIC	27.4
(d) without MMIC	42.2
(d) with MMIC	30.4

III. MECHANISM OF DECREASE OF IIP2

Fig. 6 shows a block diagram of a MCM. The MCM has a direct conversion MMIC. The hatched portion indicates elements in the MMIC, which includes all active circuits in so small area of 1.3 x 2.1 mm^2 that undesired couplings might be occurred in or around it.

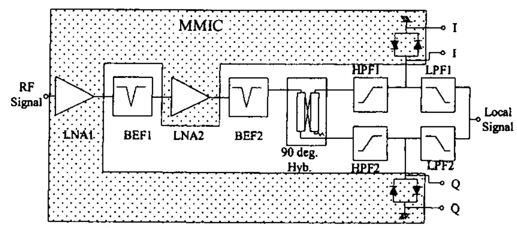

Figure 6: Block diagram of the MCM

A local signal has a half frequency of the operating RF frequency. If the local signal couples to the input of LNA1, it generates a second harmonic signal around the RF frequency. The second harmonic of the leaked local signal (2Lo) is amplified by LNA2, then go into a mixer though a 90-degree hybrid and a high pass filter.

The mixer is consists of two sets of anti-parallel diode pair (APDP). In the APDP, the even order harmonics are canceled at the terminal. When the 2Lo reaches to the APDP, the fifth harmonic

$$f_{IM2} = f_{RF1} - f_{RF2} + f_{2Lo} - f_{Lo} - f_{Lo} \qquad (4)$$

is generated in the mixer and this odd order harmonic is not canceled in the APDP. The last two terms of the equation (4) correspond to the local signal and the third term corresponds to the 2Lo that traces the path from LNA1 to the mixer.

IV. EXPERIMENTS

Table 4 shows the measured IIP2 of the original MCM that was not treated any ground. The local power was 10 dBm. The worst value of IIP2 was 4 dBm.

Fig. 7 shows experimental diagram to change coupling amplitude and phase. To simulate no coupling situation we used two MCM, one is for amplifiers and the other is for a mixer.

Table 4: Measured IIP2 of the original MCM

Local Power is 10 dBm	I-Channel			Q-Channel		
	2110	2140	2170	2110	2140	2170
IIP2 [dBm]	7.5	4	8.5	13.5	14	4.3

Base band (55kHz,70kHz)

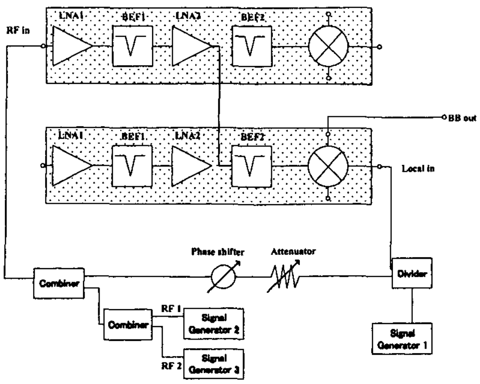

Figure 7: Experimental diagram

Table 5 shows the relation between IIP2 and the power of local signal at the input of LNA1 for the best and the worst case when the coupling took all phase variation. The power of minus infinity corresponds to the case of no coupling of the local signal to the input terminal of the LNA1. These results show that the isolation of the original MCM was less than 35dB that corresponds to the power of the leaking local signal of -25 dBm. If the isolation is improved to 50 dB, we can expect the IIP2 become more than 10.2 dBm in I-channel as worst case, even if the isolation of MMIC would remain the same level.

Fig.8 shows the measured IIP2 of the improved MCM with several RF powers from -42 to -38 dBm, and fixed Lo power of 10 dBm. Average IIP2 becomes 25.3 dBm when RF power was -40 dBm. The IIP2 has been improved more than we expected. The reason is the isolation of MMIC was so much improved from 37.4 dB shown in section II that the table 5 cannot be available to predict the improvement of IIP2.

V. CONCLUSIONS

We have shown the MCM with a flip-chipped MMIC has multi-path coupling of almost the same levels. To reduce the couplings, firm ground patterns are required on LTCC as well as shielding metal structures on MMIC. The effectiveness of introduced ground patterns and shielding structures are verified by measurements of IIP2, which was improved more than 15 dBm successfully.

Table 5: The relation between IIP2 and power of the leaked local signal at the input of LNA1

I-Channel

Base band (55kHz,70kHz) was -35.5 [dBV]

Lo power at RF terminal [dBm]	Worst case		Best case	
	IM2 (15kHz) [dBV]	IIP2 [dBm]	IM2 (15kHz) [dBV]	IIP2 [dBm]
-25	-84.5	4.1	-131.5	51.1
-30	-87.5	7.1	-100.5	20.1
-35	-89.4	9.0	-96.3	15.9
-40	-90.6	10.2	-94.3	13.9
-45	-91.4	11.0	-93.4	13.0
$-\infty$	-92.5	12.1	-92.5	12.1

Q-Channel

Base band (55kHz,70kHz) was -36.9 [dBV]

Lo power at RF terminal [dBm]	Worst case		Best case	
	IM2 (15kHz) [dBV]	IIP2 [dBm]	IM2 (15kHz) [dBV]	IIP2 [dBm]
-25	-89.0	7.1	-133.0	51.1
-30	-92.9	11.1	-130.2	48.4
-35	-95.8	14.0	-115.3	33.5
-40	-97.9	16.1	-106.7	24.9
-45	-99.2	17.4	-104.0	22.2
$-\infty$	-101.4	19.6	-101.4	19.6

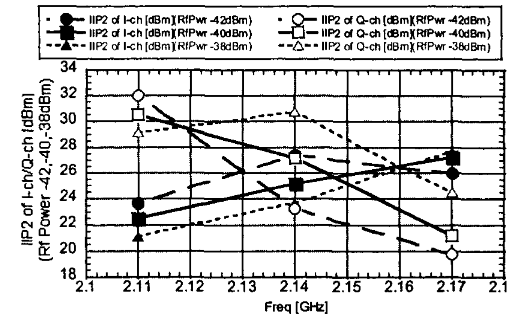

Figure 8: Measured IIP2 of the improved MCM

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