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PCS Tranceiver Module Using Monolithic Microwave Circuit On Quartz(MMCQ) Technology

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****Original title : Design and Fabrication of PCS Tranceiver With MMIC Chips And High Quality Passive Elements Integrated Using Monolithic Microwave Ceramic Circuit Technology**

Abstract

This paper deals with several GaAs MMIC chipset for PCS application and MMCC(Monolithic Microwave Ceramic Circuit) which is used for integration of bare chips with high quality thin film passive elements fabricated on quartz.

The proposed MMCC needs only small area comparable to MMIC and can eliminate the parasitics of bond wire using flip-chip bond. On ceramic substrate of MMCC, the KGD (Known Good Dies) can be attached and the performances of passive components on MMCC can be improved better by optimizing process parameters and using the substrate whose dielectric constant is very low. The yield of MMCC can be maximized by optimizing the number of transistors and passive components integrated on MMIC and chosing KGD.

MMIC chipset composed of LNA, Mixer, and VCO for PCS RF tranceiver are fabricated using 0.5um GaAs MMIC foundry provided by GEC Marconi. The measured noise figure of LNA is 1.7dB and the power gain 15dB. The measured conversion gain of down-conversion mixer is 4dB and OIP3 10.8dBm. And the upconversion mixer has its measured conversion gain 6.5dB and OIP3 0dBm. In case of VCO, the measured output power is –0.8 ~ +0.8dBm and phase noise –112dBm/MHz.

The passive components are implemented on the quartz substrate using thin film technology developed in our laboratory. The RPCVD Si_3N_4 is used for the dielectric material of capacitors, and spiral inductors are fabricated by using double layer metal. The resistors are implemented using NiCr thin film. The resonance frequencies of inductors can be increased in the quartz substrate, because its low dielectric constant (about 3.4) reduces the parasitic capacitance of inductors dramatically. In the case of 16nH inductor, the measured resonance frequency of inductor is increased from 8GHz on GaAs to 13GHz on quartz. To improve the quality factor of inductors, the width of plated spiral metal is extended from 12um to 20um. The spiral inductor up to 10 turns has been implemented on quartz and we obtain the inductance up to 65nH. This is difficult to obtain from GaAs MMIC due to its large area. The large capacitor above 40pF 350um x 350um can also be obtained easily in MMCC. The thin film NiCr resistors have their sheet resistance about 18ohm/square.

Finally, PCS tranceiver containing two LNAs, upconversion mixer, downconversion mixer MMIC and passive elements are integrated using MMCC technology. To optimize the bias of each MMICs, various pairs of voltage divider resistor are provided on quartz substrate so that we can adjust the voltage dividers to tune the gate biases of MMICs. The interconnection parasitics caused from bond wires can be eliminated by facing down and bonding the bare chip on substrate. (flip-chip bond) The Au ball bumps for flip-chip bond are formed on the pads of MMIC using ball bumping mode of ultrasonic ball bonder. We found that the flip-chip bond works quite well for the interconnection up to 20GHz. The

conductive epoxy filled via hole is used for interconnection between the ground of MMICs and that of substrate.

The size of the finished PCS tranceiver is 1cm x 1.5cm and has the following performance. The total current consumption of tranceiver is about 56mA at 5V power supply. The frequency bands are 1840 ~ 1870MHz for Rx and 1750 ~ 1780MHz for transmitter (Tx). The power gain and noise figure of receiver (Rx) is 22dB and 1.9dB respectively. The OIP3 of Rx is above 3dBm. The power gain and OIP3 of Tx is 5dB and –2dBm.

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Abstract - This paper deals with new integration technology of high quality passive elements and several GaAs chipsets using MMCQ(Monolithic Microwave Circuit on Quartz) for PCS. MMIC chipset are composed of LNA, mixer, and VCO. On quartz substrate of MMCQ, high quality passive components are fabricated using thin film process and the MMIC's are flip-chip bonded. The spiral inductor up to 10 turns has been implemented and we obtain the inductance up to 65nH. The resonance frequency of inductor is increased on quartz because of its low dielectric constant. The interconnection parasites caused by bond wire can be eliminated by employing flip-chip technique. The total current consumption of complete PCS tranceiver except the power amplifier is 56mA. The power gain, noise figure, and OIP3 of receiver are 22dB, 1.9dB, and 3dBm respectively. The power gain and OIP3 of transmitter are 5dB and –2dBm.

I. INTRODUCTION

. Recently several fully integrated microwave tranceivers on Si and GaAs have been reported.[1][2] But, in a wide range of application, some kind of hybrid approach is more attractive and easy from the performance, economy, and yield point of views. Because standard monolithic circuit blocks such as LNA, or mixer may be readily and economically available, the MCM(MultiChip Module) composed of these circuits can be implemented readily with the density similar to that of monolithic maintaining high yield. MMCQ(Monolithic Microwave Circuit on Quartz) is a kind of MCM with quartz substrate. One of the important features of MMCQ is that large inductor and capacitor of high quality factors, which cannot be integrated in MMIC can be fabricated on quartz substrate using conventional thin film technology. Quartz is used as substrate, for its low dielectric constant leads the inductor to have less parasitic capacitance and higher resonance frequency. Each known good GaAs MMIC is flip-chip bonded on quartz. Because the parasitic inductance and resistance of flip-chip ball bump are negligible up to several tens of GHz[3], flip-chip bond is a good replacement of wire bond at several GHz.

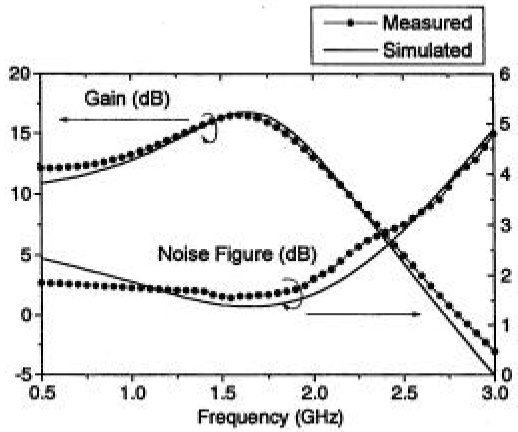
MMIC chipsets for MMCC tranceiver module are fabricated using GMMT GaAs MMIC foundry and consist of LNA, up/down mixer, and VCO. And The RF frequency of tranceiver is 1.8GHz.

II. MMIC CHIPSET FOR PCS

To fabricate the MMCC tranceiver for PCS, the MMICs such as LNA, up/down mixer, and VCO should be prepared. In this work, all MMIC chipset are fabricated using GMMT GaAs MMIC foundry. The used GaAs FET has its cutoff frequency 24GHz, and 0.5um gate length.

A. LNA

Because LNA is the first component received signal from antenna meets, it determines the noise figure and input VSWR of the overall receiver system. So the LNA is required to have low NF, low input VSWR, and high power gain simultaneously. To satisfy the above requirements, CCSF(CasCode Series Feedback) and CSSL+CGPF (Com--mon Source Inductive Series Feedback + Common Gate Parallel Feedback) schemes are chosen.[4] The measured noise figure and power gain of CCSF are shown in fig(1).

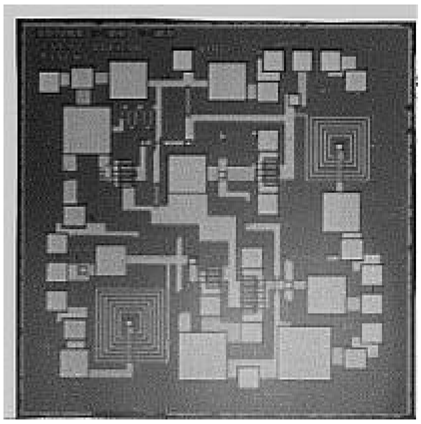


Fig(1). noise figure and power gain of LNA chip.

At 1.8GHz, the measured noise figure and power gain are about 1.7dB and 15dB respectively. The input return loss S11 at 1.8GHz is sufficiently low(below –10dB, VSWR<2). In the case of CSSL+CGPF, the noise figure and power gain are about 1.9dB and 13dB respectively. The supply voltage $V_{DD}$of LNA is 5V and current consumption is 10mA. The chip size is 2mm x 2mm.

B. Mixer

The mixer converts the frequency of the signal from the LNA output down, or up to make the RF signal fed into power amplifier. In designing mixer, the IP3 and LO to RF isolation or LO to IF isolation are important requirements. To increase LO to RF isolation, the CGCS(common gate common source) FET pair scheme is used.[5] In this scheme, LO leakage to RF or IF port is very small because the LO passed through CG cancels out the 180° shifted LO passed through CS. The measured OIP3, LO to RF isolation, and gain of down-conversion mixer are 10.8dBm, 28dB, and 9.5dB respectively. The OIP3, LO to RF isolation, and gain of up-conversion mixer are 0dBm, 10dB, and 6.5dB, respectively. The supply current is 12mA. Fig(2) shows the photograph of fabricated up-conversion mixer MMIC. The chip size is 2mm x 2mm.



Fig(2). The photograph of fabricated up-conversion mixer

C. VCO

VCO(voltage controlled oscillator) generates the frequency tunable mixing signal(LO) and the important requirements are as follows. Output power, tuning sensitivity, phase noise, and pulling figure. In this work, Colpitt's type is used. By tuning varactor connected to FET gate, the frequency of VCO can be varied from 1620MHz ~1650 MHz. The fabricated VCO MMIC is shown in fig(3). The chip size is 2mm x 2mm.

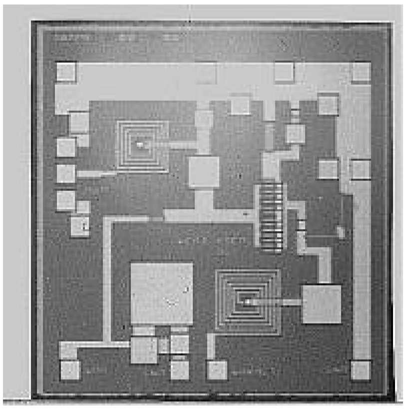


Fig (3). The photograph of fabricated VCO MMIC

The measured performances of fabricated VCO are as follows.

Output power : -0.8 ~ +0.8dBm

Tuning sensitivity : 15MHz/V

Phase noise : -112dBm/MHz

Pulling figure : < 46MHz

Supply current : 6.7mA

III. MMCQ TECHNOLOGY AND FLIP-CHIP BOND

A. Inductor

In some microwave circuits, large inductor and high Q inductor is needed. But the inductor integrated on Si or GaAs MMIC has its inductance limitation to about 20nH and its qulity factor less than about 15. However, inductor on quartz substrate has no limitation of its size. In this work, to improve the quality factor, the width of inductor is extended from 12um to 20um and the spiral second metal is plated with 2um thick Au. Furthermore, because low dielectric constant of quartz substrate allows us the lower parasitic capacitance, the resonance frequency of inductor can be improved from 13.6GHz to 23.6GHz. Fig(4) shows the measured resonance frequencies of inductor fabricated on quartz compared with those of GEC MMIC L on polyimide and those of inductor fabricated on GaAs wafer.

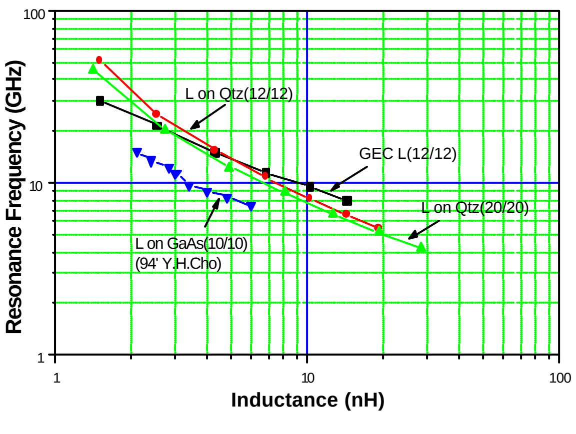


Fig (4). The resonance frequency of inductors

As shown in fig(5), the resonance frequencies of 12/12 (width/gap) and 20/20 inductors are comparable to GEC MMIC's inductor on 3.5um thick polyimide whose dielectric constant is 3.4. Besides, the measured quality factor of 12nH 20/20 inductor on quartz is about 10 at 2GHz. The maximum available inductance in MMCQ is 10turns, 64nH, but its resonance frequency is about 2GHz.

B. Capacitor

The dielectric material of capacitor is 2000A thick Si3N4 deposited by RPCVD. In this work, up to 350um x 350um sized capacitors are fabricated and thus they can be used as bypass capacitor. According to the measured parameters, we obtain the capacitance 3.2pF/100um x 100um, and about 40pF in the case of 350um x 350um.

C. Resistor

The resistor on ceramic is fabricated using 700um thick NiCr. The line widths of NiCr resistor are 10um and 20um. To etch out NiCr pattern easily, lift off is used. The measured data shows its sheet resistance is 18Ω/square. Contrary to other passives, parasites of resistor are negligible, so that simple resistor model can be used.

D. Via hole

In microstrip configuration, to connect ground on substrate to the backside, metal plated via hole is needed. Via hole through quartz substrate is formed using ultrasonic milling. Because via hole process is very dirty, it is precedent to every other MMCQ processes. To connect electrically both sides, via hole is filled with conductive epoxy. The radius of via hole is about 0.8mm and makes no problem at the operating frequency.

E. Flip-chip bond

Au bumps are formed on both chip and substrate pads for flip-chip bond using ultrasonic ball bonder. To evaluate the microwave characteristics, GaAs chip containing coplanar waveguide is flip-chip bonded on quartz and its measured S21 is compared with the simulated one. As shown in fig(5), both data coincide very well up to 16GHz and it proves the superiority of flip-chip to wire bond

.IV. MMCC TRANCEIVER MODULE FOR PCS

Using above mentioned MMIC chipsets and MMCQ technology, a PCS tranceiver module is fabricated on quar-

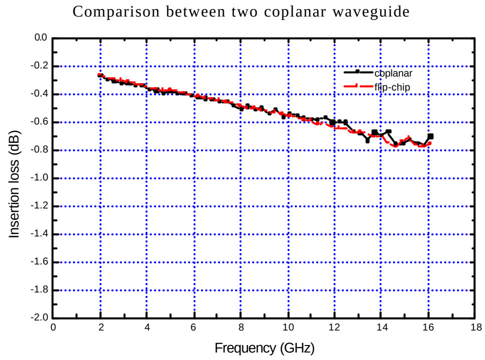
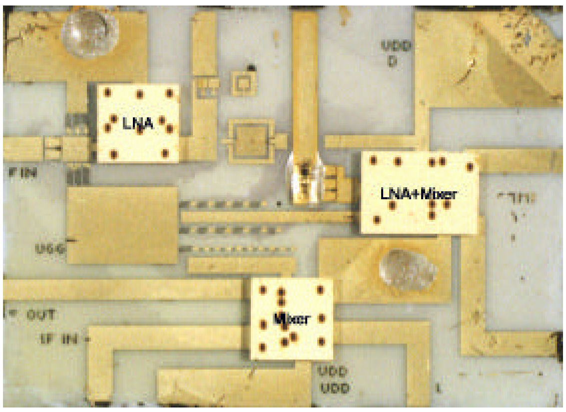


Fig.(5) Insertion loss of flip-chip vs. simulated

-tz substrate. Two types of MMCQ tranceiver module are fabricated. One contains two LNAs, down conversion mixer, and up-conversion mixer. The other contains two LNAs, down-conversion mixer, and VCO. For tuning the gate voltages of MMIC FETs, voltage dividing resistor arrays are fabricated on MMCQ. There are also bypass capacitors and inductors. Each MMIC is attached to quartz using Au bump flip-chip bond to eliminate the parasitic inductance of wire bond. Fig(6) shows the photograph of fabricated MMCQ tranceiver, whose size is 1cm x 1.5cm.



Fig(6). The photograph of fabricated MMCQ tranceiver module

To measure the small MMCQ tranceiver module, it is attached to larger PCB to which the measurement cables are connected. The measured performances of PCS tranceiver module are summarized below.

	Specification	Measured perf.
Rx RF Frequency	1840 ~1870MHz	1840~1870MHz
IF Frequency	220MHz	220MHz
Power Gain	> 29 dB	22 dB
OIP3	> 2 dBm	3 dBm
Noise Figure	< 2.2 dB	1.9dB
Tx RF Frequency	1750~1780MHz	1750~1780MHz
IF Frequency	130MHz	130MHz
Power Gain	> 4dB	5dB
OIP3	> 12dBm	-2dBm
Total current	< 80mA	56mA

Table (1). Specification and measured performances

V. CONCLUSION

A high performance PCS tranceiver module is developed using MMCQ technology, where high quality passives R, L, C are fabricated on quartz using thin film technology, several standard MMIC circuit blocks are flip-chip bonded, and finally via holes are formed using ultrasonic milling. Compared with either fully monolithic or hybrid integrated circuit approaches, our MMCQ technology is thought to have unique advantages from the performance, cost, and time-to-market point of view.

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