A Proposal of Field-Programmable RF Gate Array Devices

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Abstract: A novel RF configurable device composed by bare-chip, bumps and board are proposed. We call this "Field-Programmable RF Gate Array (FPRA)," This device, a kind of programmable system packages, has a potential to be applied to wireless communication terminals such as software-defined radio.

1. Introduction

Recently, high-density packages are becoming seamless, *i.e.*, roles in wiring among chip, package and board have overlapped mutually. This leads to multi-chip-modules (MCM), chip-size-packaging (CSP), and multi-layer printed-wiring-board (PWB) bonded with them. On the other hand, digital/analog programmable devices such as FPGA (field-programmable gate array)[1], FPAA (field-programmable analog array)[2], have developed and commercially spread widely because of their cost-effective re-configurability due to the progress in silicon miniaturization/mass-production. However, there are few reports on RF configurable devices[3,4], nor on RF re-configurable devices. In this paper, a novel concept of RF programmable devices, a kind of system package using bare-chip, bumps and PWB, is proposed. This device, named as field-programmable RF gate array (FPRA), is aimed for GHz communication. The further development of this device, merged with digital devices, has a potential to play a great role in low-cost software-defined-radio (SDR) terminals for ubiquitous network system. We call this advanced device field-programmable system-package (FPSP).

2. Field-Programmable RF Devices

Figure 1 indicates a concept of the proposed field-programmable RF gate array (FPRA), and Table I lists the comparison of features of 3 kinds of the programmable devices[1,2]. The configurable block, an essence of programmability, is named CRB (configurable RF block) for our FPRA, corresponding to CLB (configurable logic block) and CAB (configurable analog block) for FPGA and FPAA, respectively.

One of difficulties in RF analog design exists in Rf impedance matching. CRB consists of several FETs only. I/O buffer amplifier in FPAA, which is required for wide-range linear characteristics, corresponds to RF matching I/O in our FPRA. The FPRA consists of CRB, matching I/O, switch array, and PWB. The key concept in FPRA is that configurability is realized with not on-chip, but on-board wiring,.

3. Discussion

The features of the proposed FPRA are as follows;

i) on-board wiring with lengths designed within several millimeter,
ii) RF-CMOS FET array as configurable RF blocks (CRB),
iii) RF matching I/O composed of inductances and capacitances,
iv) flip-chip bump-bonding of bare-chip onto PWB,
v) FET switch array for re-configurability.

i) on-board wiring

Total area of FPRA is limited within several millimeter square. The reason is that wiring can be designed under the conventional RC delay consideration when wiring length is less than 1/40 of signal wavelength[5]; several millimeter on high-ε PWB at GHz. It is noticed that wiring among CRB chips, causing programmability, is performed by using on-board wiring. Its cost- and area- performances can be not lower than that by using switch matrix in FPGA and FPAA.

ii) RF-CMOS FET array as CRB

The CRB chip is flip-chip bonded to on-board wiring via bumps on PAD, as compared in FPGA on-chip wiring. In CRB, the desired RF function FET blocks such as power amplifier, amplifiers+mixer+filter, etc. are determined by means of selecting bump-bonding PADs, and on-board wiring conncting them. Figure 2 shows examples of combined FETs as RF functional blocks. Recent silicon progress makes RF-CMOS applicable to GHz wireless application.[6] It is noted that various RF function blocks

can be composed by simply combining MOSFETs. For example, nMOS+pMOS becomes push-pull amplifier (Fig.2a)[7], and two FETs become both dual-gate FET mixer (Fig.2b) and active inductor (Fig.2c)[8]. Figures 2(a)-(c) also indicate simulated results of RF characteristics. The active inductor is also used for iii) RF matching I/O, and can also used for composition of the active filter. RF-FET switch, commonly utilized for antenna switch in digital cellular phone, is also composed of FET combination.

iii) RF matching I/O

One of difficulties in RF design exists in impedance matching of each active device. Analog IF OP amps, composed by many transistors of the order of ten, therefore will not operate at GHz-band. Whereas, in CPB of our FPRA, each functional component consists of one or a few transistors. Then the impedances of all kinds of FET-combinations used are examined beforehand, and each combination is wired to matching I/O to adjust impedance also using on-board wiring. The matching I/O consists of several inductors and capacitors, and several variable active reactances. Moreover, for re-configurability, redundant on-board wirings should be prepared. In operation, they are switched by v) RF-FET switches for desired communication functions.

iv) flip-chip bump-bonding of bare-chip onto PWB

For the compact packaging within several millimeter square, the conventional wire-bonding should not utilized from the viewpoint of both area-effectiveness and GHz signal transferring. Here, the flip-chip bump-bonding of bare-chip onto PWB are adopted. The high-frequency characteristics of bump have not been investigated in detail. Figure 3 shows simulation results of high-frequency characteristics of bump. For 100μm-diam.-bump, the scattering parameter S21, which is a transition coefficient or propagation loss, are found to be –0.1dB at 20GHz. It is considered that 100μm-diam.-bump is applicable to GHz-signal-transfer system such as bluetooth, IEEE802.11b, and third generation wideband CDMA cellular system. Total performance of the proposed packeges including GHz-bump bonding will be discussed.

Multi-layer PWB can also include passive components, assisting a function of iii) matching I/O block.

v) FET switch array for re-configurability

The software-defined radio (SDR) must receive various waves and demodulate desired signals. On considering our FPRA applied to the SDR, real-time re-configurability is an indispensable function. For the re- configurability, FET switches is considered to act as switches of wiring paths. In our FPRA, the FET switches are used for switching wiring paths. RF-FET switches are commonly utilized as antenna switches in digital cellular phone, and are simply composed of FET combination.

4. Conclusion

In this paper, novel field-programmable RF gate array devices are proposed and named "FPRA." The FPRA consists of CRB, matching I/O, switch array, and PWB. Focused on GHz-communication, the CRB of RF-CMOS FET array operates as several RF functional blocks by selecting the position of PAD bumping and designing on-board wiring.

The proposed FPRA package is effective for needs of low-cost configurable RF devices, real-time re-configurable FPSP for the SDR terminals, environmental endurable auto-gain-control low-power intelligent RF systems.

References

[1]e.g. http://www.xilinx.com

[2]e.g. http://www.anadigm.com

[3]T. Tokumitsu, et al., IEEE Microwave & Guided Wave Lett. 5, p.411(1995)

[4]e.g. http://www.agere.com

[5]K. Tsubouchi, et al., IEICE Trans. Electron. E84-C, p.1730.(2001)

[6]I.Yoshida, Tech Dig. IEDM '97, p.51.

[7]M. Yokoyama, et al., Jpn. J. Appl. Phys. 39, p.2463(2000)

[8]S. Hara, et al., IEEE Trans. MTT, 37, p.1979(1989)

Table I. Comparison of programmable devices.

	FPGA[1]	FPAA [2]	FPRA(proposed)
Functional block	CLB	CAB	CRB
	Configurable Logic Block	*Configurable Analog Block*	*Configurable RF Block*
Components	Logic gates	OP Amps	FETs
	Wiring matrix	I/O buffer	Matching I/O
	Memory	Wiring matrix	On-board wiring, Switches
Operation freq.	Digital	Analog(MHz)	RF analog(GHz)

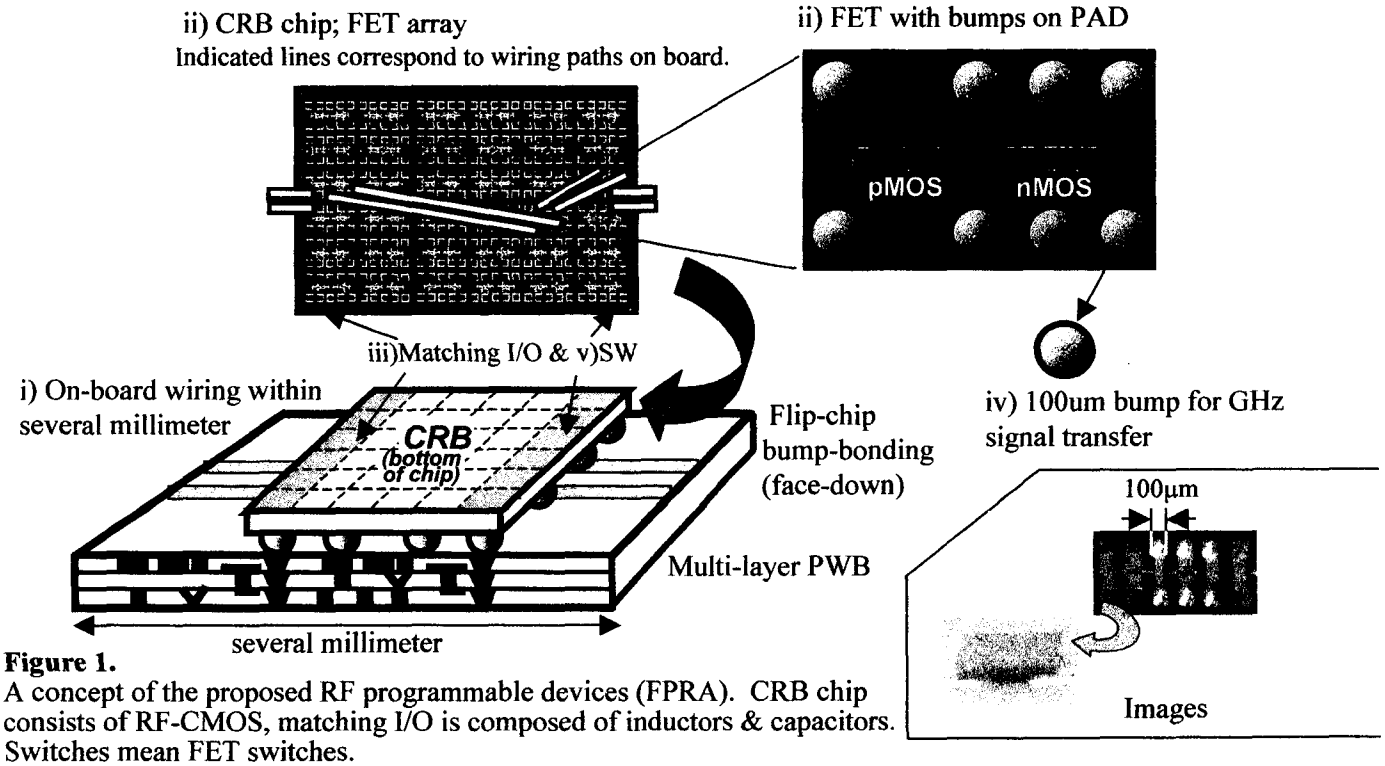

Figure 1.
A concept of the proposed RF programmable devices (FPRA). CRB chip consists of RF-CMOS, matching I/O is composed of inductors & capacitors. Switches mean FET switches.

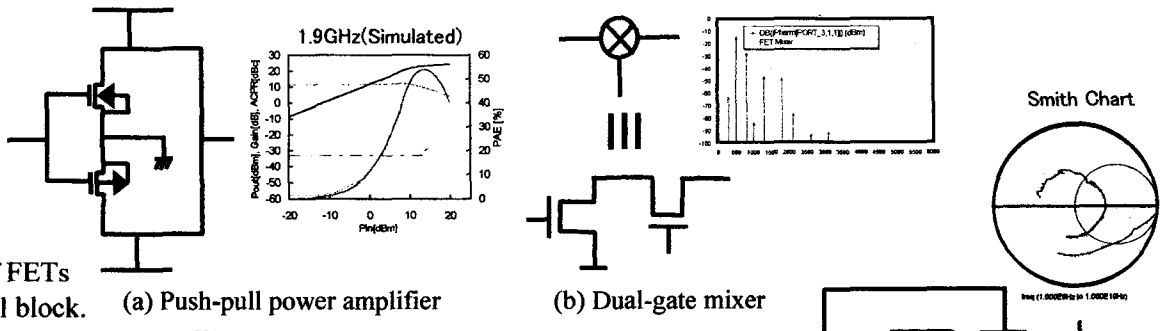

Figure 2.
Combination of FETs as RF functional block.

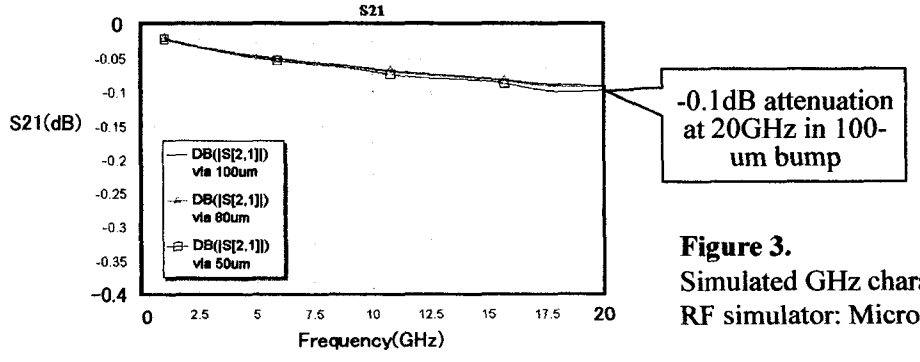

Figure 3.
Simulated GHz characteristics of bumps. RF simulator: Microwave office 2001®