Mixed Mode Silicon-on-Insulator MMIC Technology for digitally controlled RF/Microwave Systems

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ABSTRACT
A high performance mixed mode Silicon-On-Insulator (SOI) IC process has been developed providing the ability to integrate digital, analog, RF and microwave circuitry on the same substrate. Standard functions such as microprocessor bus interface logic and microwave lumped/distributed circuits for 2.4/5.8GHz are described along with related system-on-a-chip implementations. Using this technology, digital microprocessor controlled system architectures can be developed quickly without the need for interfacing between control logic control, data and programming ports of the analog/microwave hardware.

INTRODUCTION
Advancements in a low cost SOI semiconductor process offers the ability to integrate digital CMOS functions with RF/microwave lumped and distributed circuit designs for applications spanning DC to 10GHz. This cost effective IC process provides an approach bridging between high performance RF front-ends and low power CMOS digital processing. This paper discusses the IC process, design examples and the advantages of systems with direct microprocessor control of RF/Microwave hardware.

MICROWAVE / MIXED MODE IC SOI PROCESS
The SOI process offers standard features typically associated with low-power digital circuits. Because of the insulating properties of the SOI substrate, RF/microwave circuits using low loss interconnects and transmission lines are readily achievable. Both lumped and traditional distributed designs methodologies are available to the designer. The process supports a wide variety of devices described in the table below.

Device Category	Devices	Comment
0.35um CMOS	NMOS PMOS NMOS depletion	Ft > 35GHz, Fmax > 55GHz Ft > 20GHz High current density / linearity
LDMOS	NMOS	Support for high power RF
LPNP	Gated LPNP	Voltage references, beta > 15
Digital Library	0.8 / 0.5 um N/P	Standard cells for digital structure synthesis and autorouting
Diodes	Schottky Varactor PIN	High frequency mixers Tuneable structures / VCOs 60 V breakdown , switches
Capacitors	MIM MIS	1.9 fF/um^2 0.51 fF / um^2
Inductors	2 Layer metal	Q > 10 for 2nH @ 5.8GHz
Resistors	Polysilicide Single Crystal	1.75 ohms/sq & 50 ohms/sq 575 ohms/sq & 5750 ohms/sq

Using the 0.35um SOI FETs and passive RLC elements, high performance RF/Microwave circuits beyond 6GHz may be implemented along side of digital functions implemented using the standard cells of the 0.8/0.5 um digital library. Isolation for mixed mode implementations is maintained by the intrinsic properties of the SOI substrate with additional protection available as needed through the use of N/P guard rings. Figure 1 illustrates the significant advantage of SOI implementations.

DESIGN EXAMPLES

Key to implementing digitally controlled microwave circuits is the ability of the process to support high performance circuits at the frequencies of interest along with standard digital implementations. Having previously demonstrated mixed mode operation within previous versions of this process, our efforts concentrated on the creation a family of amplifiers, VCOs and mixers to explore high frequency operation. Designs were targeted between 5 and 6 GHz and structured for low voltage/low current operation. An LNA, feedback amplifiers, active matching circuits, varactor controlled VCOs and Gilbert cell style double balanced mixers were all designed and fabricated. Typical conditions provide for < 3 volt operation with currents ranging between 4-10mA supporting 1dB power compression near 0dBm. Performance and pictures of a single stage broadband feedback amplifier and a double balanced mixer are shown in figures 2-5. This level of performance is readily attainable showing the potential for advanced integrated radio front-ends operating up to 6GHz, covering many of today's commercial operating bands.

DIGITALLY CONTROLLED RF SYSTEMS

Historically RF and microwave assemblies have relied upon power switches, UARTs and static control lines to provide the data and power interfaces, well short of significant data handling or signal processing. The ability to mix digital control and signal processing on the same substrate can provide several benefits seen in the immediate reduction of discrete parts, digital interface logic and power switches. Figure 6 illustrates the relative advantages of moving from discrete implementations to mixed mode and eventually into system-in-a-package or system-on-a-chip concepts. The significant size/cost savings shown in figure 6 are based on trends within Honeywell's short-range wireless control products as we have striven to make wireless control cost effective for a wide range of consumer products. More aggressive reductions in cost/size would be expected for systems with higher levels of complexities such as wireless LANs and personal communication devices.

A secondary benefit is to use digital bus interfaces allowing non-RF engineers the ability to directly program and control the operation of a RF system. In this fashion system development time will be decreased as functions can now be directly controlled without the need for developing intermediary hardware/firmware interfaces. Figures 7-8 illustrate a digitally controlled attenuator controlled through a clocked digital interfaces currently being developed.

A more complete implementation of these savings can be seen in our previous development of a 928MHz single chip radio employing a standard bus interface. Here direct access across a serial peripheral interface (SPI) to a microprocessor provides for all control and transfer data to and from radio ASIC. The radio ASIC performs many digital functions: data detection, demodulation, retiming, encode/decode, data buffering and handles the synthesiser programming registers. The next step in this development is to extend architectures of this type using SOI technology for operation in higher frequency bands, such as 2.4 and 5.8 GHz ISM allocations.

CONCLUSION

The technology is now available to provide single chip solutions for the majority of RF/Microwave system implementations with direct connections to microprocessor bus interfaces. The ability to reduce system development time by controlling RF/Microwave hardware with high level microprocessors languages holds the promise of faster time to market smaller implementations. Additionally the capabilities demonstrated with this microwave SOI technology illustrates the ability to simultaneously achieve high levels of integration, high performance and low power dissipation using a low cost silicon based technology at frequencies beyond 6GHz.

ACKNOWLEDGEMENT

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ILLUSTRATIONS

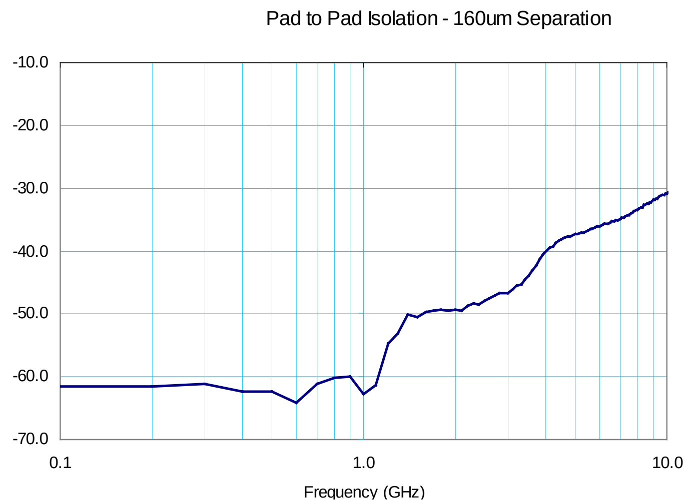


Figure 1. Isolation (dB) at a distance of 160um

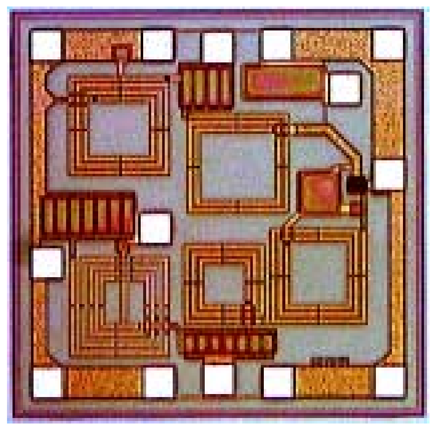


Figure 2. Single Stage SOI feedback amp

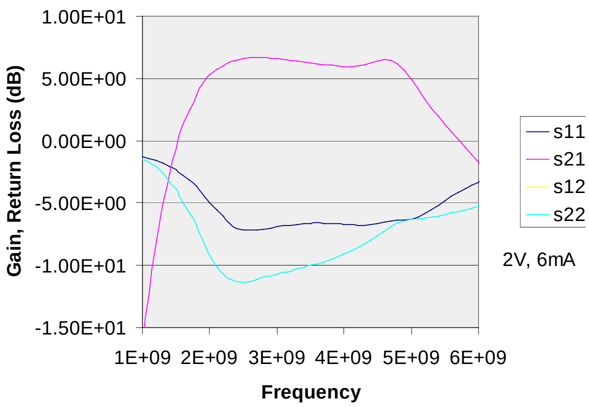


Figure 3. Single stage SOI feedback amp response

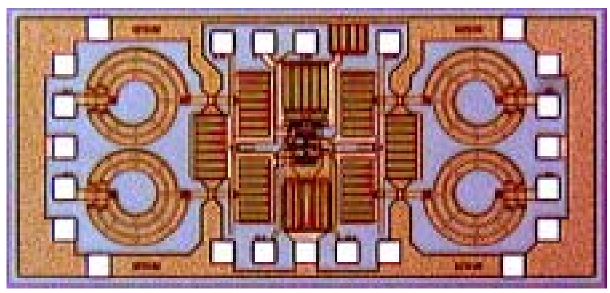


Figure 4. Double balanced SOI mixer

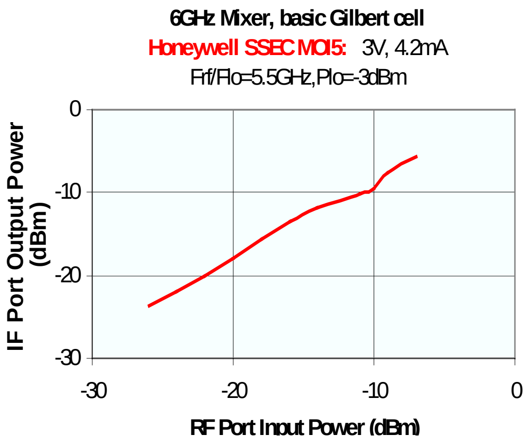


Figure 5. Double balanced mixer Pin vs Pout

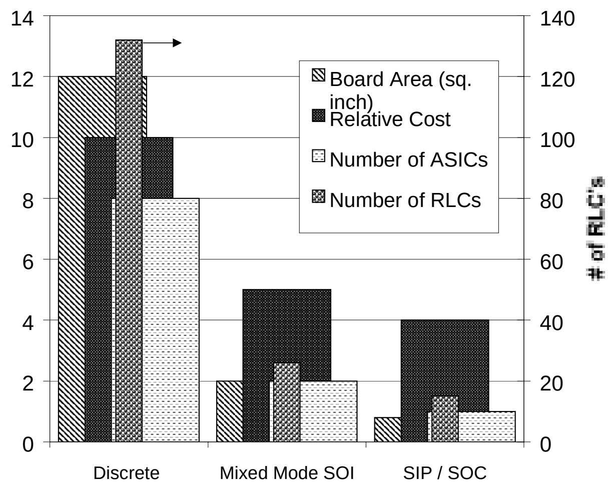
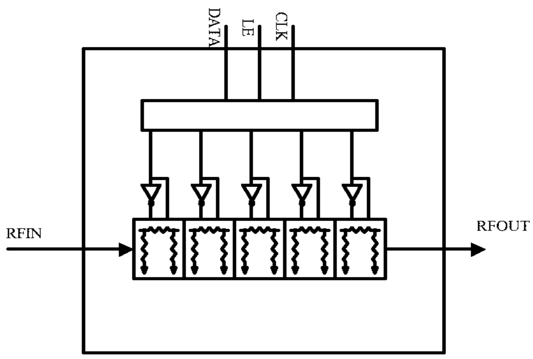
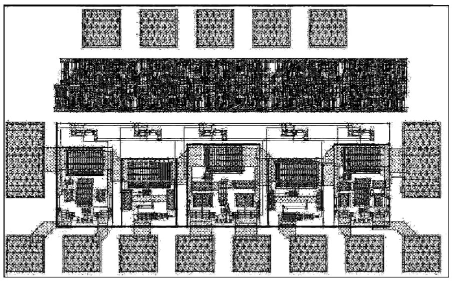
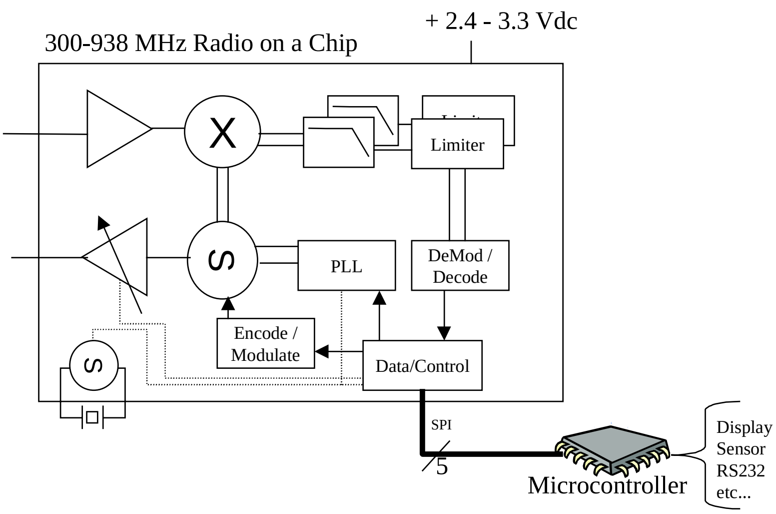


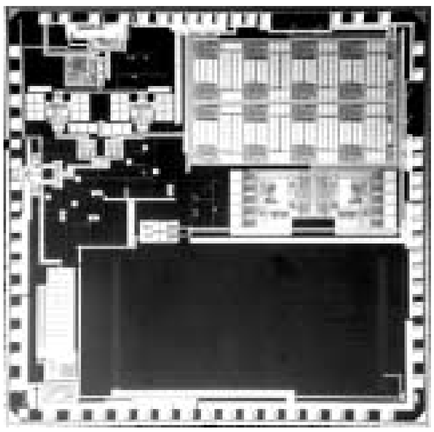
Figure 6. Mixmode integration savings





Figures 7, 8. Using SOI, a digital interface and mixed mode layout is currently under development for a 5 bit variable attenuator for applications up to 3GHz





Figures 9, 10. Architecture and photograph of a 928MHz “radio on a chip” using a SPI digital interface for all control and data handling. The SPI port is the only connection to the system, with all operating modes programmable.