RF-MEMS and RF-MST for Advanced Communication in Europe

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Abstract – **Wireless solutions at radio, microwave and millimeter wave frequencies continue to show growing interest in consumer and military applications. Present limitations inherent to the capabilities of conventional components are expected to be overcome by a new class of devices called Radio Frequency Micro-Electro-Mechanical Systems (RF MEMS). Based on the Micro Systems Technology (MST) and fabricated by using semiconductor micromachining techniques, RF MEMS promise to overcome such limitations and to add new functionalities. Although in many cases improved performances have already been demonstrated, intense research efforts are still required to enable their penetration into the market. Such efforts have been and continue to be tackled in Europe by several public, private, national and EU founded R&D programs. An overview of such initiatives and of the relevant challenges will be given hereby, along with the envisioned roadmap toward RF-MST integration of future advanced RF-frontends and transceivers. Their pervasive deployment into ubiquitous terrestrial and space communication, ambient intelligence, security, transportation is hinged to a cost-effective miniaturization of both conventional and new functionalities such as redundancy and reconfigurability, for which hybrid technology and novel materials may be required. Eventually in order to leverage their insertion into practical applications industrial qualification and reliability standard still need to be met.**

1 INTRODUCTION

THE 1990's have brought a profound change in radiofrequency (RF) technology driven largely by the information age which has created a heightened interest and worldwide market for communication systems and networking of voice and data alike. A change from long-range systems, having large RF transmitted power, to shorter range systems, having relatively modest RF power has been observed. The paradigm for these new systems are the cellular wireless networks consisting of a single smart base station feeding a local cell of handsets acting like individual terminals or nodes of the network. Nowadays most of the wireless communication standards (such as the GSM, UMTS, Bluetooth, WLANs), as well as position and tag identification techniques (such as the GPS and RFID) are allocated in the frequency range up to 5GHz. Extensions up to 10GHz are currently being considered for low power applications in ultra wide band (UWB) and metropolitan area network (such as the IEEE 802.15.3a and the WiMAX IEEE 802.16d/e respectively). All such systems are intended to form a web of multiple standards able to provide seamless and ubiquitous communications, and sensing and identification capabilities. In order to cope with this complex and widespread environment, emphasis on more affordable and integrable technology, based on hybrid and novel materials and technologies is at stake. The impressive progress achieved in the last few decades by the micro-fabrication techniques based on silicon machining (both surface and bulk), has open the door to the Micro System Technology (MST). Through the MST an entire class of traditionally cumbersome RF solutions (such as relays, inductors, capacitors, filters, antennas,…) have been miniaturized down to the micro and nanometer scales and integrated along with RFICs. RF MST has enabled the introduction of electromechanical capabilities which have greatly extended the degree of RF functionality per unit volume of RF MEMS. Besides other properties such as linearity, low power consumption, and low loss, the electrically controlled mechanical configurability represents the main characteristic of RF MEMS. At the same time, MEMS present a massive dissemination potential into the marketplace thanks to the VLSI common design and batch processing methodologies. In Section 2 an overview of research and development efforts all over Europe is presented while the present limitations and open challenges that still hamper the massive introduction of RF MEMS technology into market will be finally given Session 3.

2 OVERVIEW OF THE R&D EFFORTS

Sustained by military interests, RF MEMS research and development has first experienced a significant leap in the mid 1990s in the USA. Fuelled by the booming mobile communication industry, in the late 1990s RF MEMS was believed to become the only pervasive and enabling technology for future integrated transceivers [2]. The saturation of the mobile communication market in combination with the emerging novel solutions and increasingly

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efficient semiconductor technology (such as PIN diode with

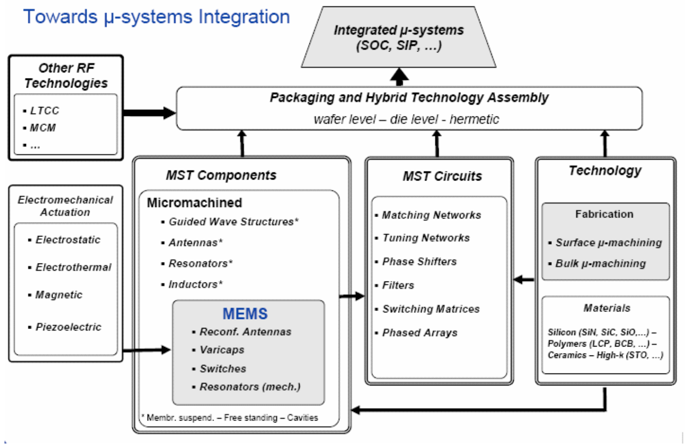

Figure 1: RF MST Technology integration roadmap [4].

improved linearity and losses), has brought the RF-MEMS community in USA first and in Europe later on, to a more realistic and niche application-oriented approach. R&D efforts still spread all over a great variety of RF MEMS devices and solutions, but only a few, such as switches, varicap and film bulk acoustic resonators (FBARs), are believed to be irreplaceable for their superior qualities.

In Europe in particular there are several activities which have been intensifying in the last seven years and are split between private industrial and public national and EU funded initiatives. The common aim is to find the way to market for RF MST devices and systems. An overview of the technology roadmap RF MST research is shown in Fig 1. The combination of hybrid technology materials and assembly techniques (packaging) are the key elements to leverage microsystem integration in the form of system-in-package (SiP) and later on systems-on-chip (SoC) final product (such as front-end or entire transceiver).

2.1 RF-MEMS in EU Industry

Although the first paper on RF-MEMS dates back to 1979 [1], the RF MEMS technology is still quite young. Among the big European industrial players with strong involvement history into RF MEMS we can find Robert Bosch (D), and DaimlerChrysler (D) both into the automotive electronics; other such as Infineon (D), ST-Microelectronics (F), Epcos (D), are more into the very low costs and massive mobile communication market, while defence and space related companies such as Thales Alenia Space (F-I), and the British BAE Systems, may afford to aim at more sophisticated and expensive solutions. While some of these companies have slowed down their RF-MEMS activities (as Daimler-Chrysler), and are now more inclined to wait for commercial products to become available, some other, have only later on successfully started RF MEMS activities (as EADS in 2003). However, with the exception of the few examples coming from USA (3 USA companies for RF Switches and 2 for FBAR, with the only European exception represented by Infineon), very few products are presently available for commercialisation, and most of them have still to fully meet reliability and packaging standard qualification requirements [3].

2.2 RF-MEMS in EU Public Initiatives

In the European research scenario RF MEMS have been occupying in the last few years an increasingly dominant position. Noteworthy are the initiatives supported and funded by the European Commission (EC) under the 5th 6th and currently under the 7th Framework Programs. A total of 24 initiatives such as integrated projects (IP), specifically targeted research projects (STREP) and networks of excellence (NoE) dealing with MST for communication and sensing applications have been co-funded by the EC along with organizations from the member states. Among these projects, some are strongly focusing on RF MEMS technology and applications. Hereby follow a brief overview of these projects, extensively documented under the EC web portal [5]: MIPA a project dealing with MEMS based integrated phased array antennas; WIDE-RF targeting wide band (800MHz-10GHz) on-chip programmable RF-MEMS devices; MEMS2TUNE aiming to develop a metal-to-metal MEMS technology platform and design methodology for switchable/tunable passive RF modules for wireless communication applications up to 6GHz; ARHMS focuses on advanced RF subsystems exploiting high power MEMS; Nanotimer aiming to develop oscillators (in the range of 10 – 1500 MHz) with high accuracy incorporating a packaged MEMS resonator; MIMOSA targeting low-power MEMS-based RF components for creating a mobile centric platform for ambient intelligence applications; ACE, the European antenna center of excellence, which covered RF MEMS applications for antenna and feeding network level in order to obtain advanced multibeams and multiband reconfigurable systems. More recently further initiatives have been funded by the EC for tackling issues in advanced research topics such as RF nanosystems (NANORF project) or in order to provide a more accessible foundry service with multiple technology manufacturing and design platforms (RFPLATFORM project). Other projects have been conceived and funded as specific support actions to draw technology market-oriented roadmaps in the field of RF MEMS (ARRRO project). Eventually AMICOM the European network of excellence in advanced MEMS for RF and millimetre wave communication which constitutes the largest and most emblematic focused initiative on RF MEMS and related issues (www.amicom.info).

Among the most remarkable achievements enabled by AMICOM there are:

- A European technology platform based on 4 EU foundries and providing different multiple project wafer (MPW) RF-MEMS solutions
- A European network of training (yearly summer school on RF-MEMS/MST) and dissemination (MEMSWAVE Symposium and specialized workshop and brokerage event at major conferences)
- A number of innovative and ambitious explorative projects in the area of: analog spectrum processing with reconfigurable front end for mobile communication terminals (0.8-6 GHz); of reconfigurable reflect array and printed antennas in the range of 24-36GHz; directive and high bit rate radio identification at millimetre wave at frequency above 60GHz with RF-MEMS enhanced front end.

  These projects target key applications in three different frequency range where MEMS are considered as enabling technology.
- A Forum of Expert which will be responsible to maintain alive and interconnected this multidisciplinar and varied RF MST/MEMS communityin Europe beyond AMICOM funding period (2004-2007).

These initiatives have created a network of competences and co-operations which spans all over Europe (including Eastern countries such as for instance Romania and Poland) and involves the main European MST players in the area of RF MEMS.

Among the

3 CHALLENGES AND LIMITATIONS

The lack of return to market of the RF MEMS research investment is a clear evidence of still open issues and limiting factors, such as, among others, the reliability, the packaging and the power handling. In spite of the fact that existing solution for packaging and power handling have been successfully demonstrated we cannot speak of industrial maturity and of price acceptance for the few existing products.

Even more serious is the problem of low reliability due to dielectric charging and contact wearing which affects electrostatically actuated RF MEMS switch and resistive contact respectively. Although such phenomena have been quite extensively investigated and characterized no real solutions are available yet. Charge trapping effects in the dielectric layer lead to a built-in voltage which may results in permanent failure due to stiction of the contacts caused by the induced electrostatic force [6, 7]. In the case of resistive switches the occurrence of microwelding and dielectric formation at the metal-to-metal contact interface yield sticking and contact resistance degradation [8, 9]. Although lifetime of few 100 billion cycles have been reported for RF MEMS switches [10], such results are usually limited to tests under laboratory conditions without a structured statistical approach. Component qualification data covering lifetime/reliability under various environmental conditions, *e.g.,* aging at high temperatures, temperature cycling, extreme humidity conditions, low temperature, influence of shocks and vibrations have not been reported yet. In Europe reliability and failure analysis of RF MEMS switching devices has only recently the subject of targeted investigation mainly driven by defence and space agency as the European Defence Agency (EDA) and the European Space Agency (ESA]. It is in fact widely accepted that reliability of RF MEMS technology must be addressed with a failure and application driven analysis with a variety of tools and methodology in not readily available, and currently under development.

Packaging is another very critical issue which strongly limits the application scenario of presently available devices. Wafer-level or 0-level packaging is increasingly becoming the preferred packaging solution also for RF-MEMS, as it enables the protection of single devices or entire modules by means of cost-effective batch processes. Two general approaches, namely the "thin-film capping" and the "chip-capping", have been adopted [11]. For the latter, it is common practice to bond a recessed capping chip onto the MEMS device wafer, whereas for the former, a thin film is used as a capping layer. In either case the package has to satisfy certain requirements, including, hermeticity, a low temperature budget, low RF losses, easy integration with front-end (RF MEMS) process and sufficiently high mechanical strength.

A further limitation which however affects only a limited number of applications is the capability to withstand high RF power levels. It has been recently experimentally demonstrated, that RF power level levels of few watts in K-band is already inducing serious temperature rise above 150°C [12]. Although some commercial products have appeared on the market (Teravicta has 30W peak level qualified SPDT in 2007), applications at high power levels (beyond 10W CW power) remains rare. Improvement beyond present limits would necessarily need attentive electro-thermo-mechanical analysis and optimization. Much is expected also from the material science even though exotic solutions may be not compatible with standard processes and hence not accepted.

4 CONCLUSIONS

Despite the difficulty in bridging the gap between R&D and the market, RF MST remains a very promising technology. As future and advanced communication systems approach the convergence of multi-standard and multi – band services on the same equipment, be it a base station or a hand-held terminal, superior frequency agile capabilities become imperative. Among the RF MST and MEMS components, switches, varactor and tuneable inductors (called also variometers) represent the key devices for enabling accurate and sophisticated analog processing. Their insertion is foreseen into reconfigurable filters (Rx/Tx so as at base band), tuneable pre/post selectors, reconfigurable multi band synthesizers, reconfigurable matching networks, multi-band PAs [13]. The European efforts in the field of RF MEMS are quite numerous, enforced by a number of initiatives supported at EU level by the European Commission, space and defence agencies. A recently funded organization called the AMICOM forum of Expert (spin off of the homologue and aforementioned network of excellence AMICOM) will be responsible to maintain alive and interconnected this multidisciplinar and varied RF MST/MEMS communityin Europe. Regarding the challenges still open, reliability represents the most critical issue, with the limitations due to the dielectric charging and lack of lifetime prediction and acceleration methods. Along with reliability, packaging and power handling constitute further research areas where efficient solutions are sought. Eventually qualified foundry processes and associated product design kit are the ultimate urgent demand from RF-MST end user and system integrator. From their availability and price acceptance depends the future of the RF MEMS technology in the coming years.

5. ACKNOWLEDGMENTS

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