Wideband RF Modules and Antennas at Microwave and MM Wave Frequencies for Communication Applications

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Abstract— **Communication and Radar industry in microwave and mm wave frequencies is currently in continuous growth. Radio Frequency modules such as Front End, Filters, Power Amplifiers, Antennas, Passive Components and Limiters are important modules in Radar and communication links. Accurate design of mm wave RF modules is crucial. Several wideband RF modules and W band detection array are presented in this paper.**

Index Terms— **Microwave and mm wave frequencies, RF modules, Communication systems, MMICS**

I. INTRODUCTION

Communication and Radar industry in microwave and mm wave frequencies is currently in continuous growth. Radio Frequency modules such as Front End, Filters, Power Amplifiers, Antennas, Passive Components and Limiters are important modules in Radar and communication links, see [1-7]. The electrical performance of the modules determines if the system will meet the required specifications. Moreover, in several cases the modules performance limits the system performance. Minimization of the size and weight of the RF modules is achieved by employing MMIC and MIC technology. However, integration of MIC and MMIC components and modules raise several technical challenges. Design parameters that may be neglected at low frequencies cannot be ignored in the design of wide band integrated RF modules. Powerful RF design software, such as ADS and HFSS, are required to achieve accurate design of RF modules in mm wave frequencies. Accurate design of mm wave RF modules is crucial. It is an impossible mission to tune mm wave RF modules in the fabrication process.

Microwave and MM Wave Technologies

- MIC, Microwave Integrated Circuits
- MMIC, Monolithic Microwave Integrated Circuits
- MEMS
- LTCC

II. MIC- MICROWAVE INTEGRATED CIRCUITS

Traditional microwave systems consists of connectorized components (such us Amplifier, Filters and Mixers) connected by coaxial cables. These modules have big dimensions and suffer from high losses. Dimension and losses may be minimized by using Microwave Integrated Circuits, MIC technology. There are three types of MIC circuits, HMIC, standard MIC and miniature HMIC. HMIC is a Hybrid Microwave Integrated Circuit. Solid state and passive elements are bonded to the dielectric substrate. The passive elements are fabricated by using thick or thin film technology. Standard MIC use a single level metallization for conductors and transmission lines. Miniature HMIC use multilevel process in which passive elements such as capacitors and resistors are batch deposited on the substrate. Semiconductor devices such as amplifiers and diodes are bonded on the substrate. Fig. 1 presents a Ku band MIC receiving link. Fig. 2 presents the layout of the MIC receiving link. The receiving channel consists of a MMIC Low Noise Amplifier, Filters, a MIC Dielectric Resonant Oscillators and a diode Mixer.

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III. MONOLITIC MICROWAVE INTEGRATED CIRCUITS- MMICS

Monolithic Microwave Integrated Circuits are circuits in which active and passive elements are formed on the same dielectric substrate, as presented in Fig. 3, by using a deposition scheme as epitaxy, ion implantation, sputtering, evaporation and diffusion.

MMIC Design Facts

MMIC components can’t be tuned. Accurate design is crucial in the design of MMIC circuits. Accurate design may be achieved by using 3D electromagnetic software. Materials employed in the design of MMIC circuits are GaAs, InP, GaN and SiGe. Large statistic scattering of all electrical parameters cause sensitivity of the design.

FAB runs are expensive, around $200,000 per run. Miniaturization of components yields lower cost of the MMIC circuits. Fig. 4 presents MMIC design flow.
Designer goal is to Comply with customer specifications in one design iteration.

A. *MMIC Technologies Features*

- 0.25 micron GaAs PHEMT for power applications to Ku Band.
- 0.15 micron GaAs PHEMT for applications to high Ka Band.
- GaAs PIN process for low loss power switching applications.
- Future new process- InP HBT, SiGe, GaN ,RFCMOS, RFMEMS

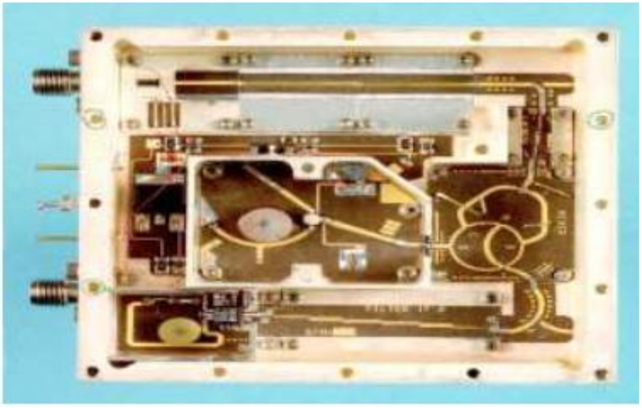

Fig. 1: Ku Band MIC-MMIC Receiving Link

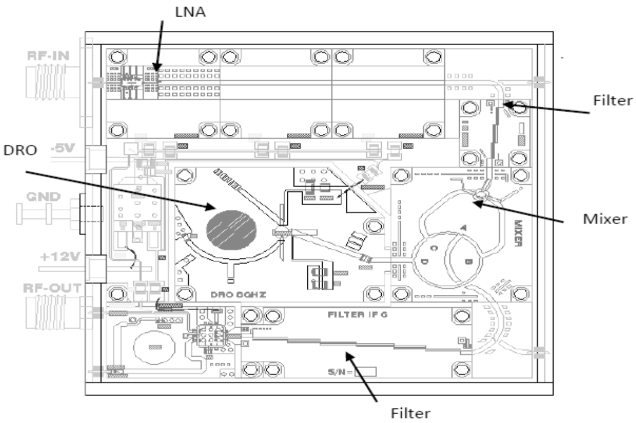

Fig. 2: Layout of the MIC-MMIC Receiving Link

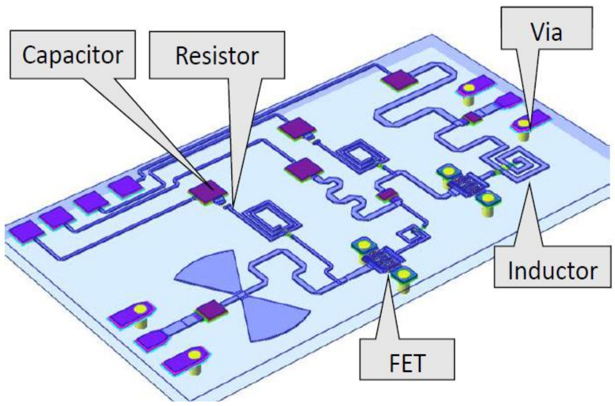

Fig. 3: MMIC basic components

Fig. 5 presents a GaAs WAFER layout. Wafer size may be 3", 5" or 6" .

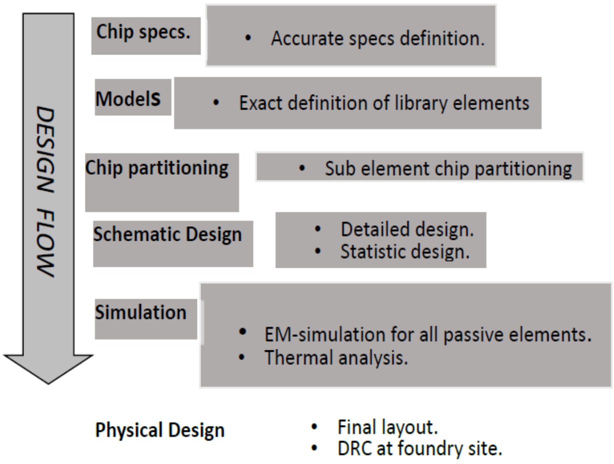

Fig. 4: MMIC design flow

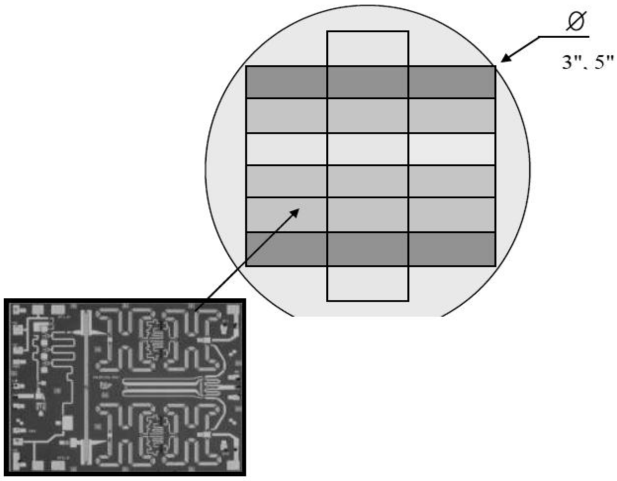

Fig. 5: GaAs WAFER layout

B. Types of Components Designed

- Amplifiers - LNA, general, Power amplifiers, wideband power amplifiers, Distributed TWA
- Mixers - balanced, Star, sub-harmonic
- Switches - PIN, PHEMT, T/R matrix
- Frequency multipliers - active, passive
- Modulators - QPSK ,QAM (PIN, PHEMT)
- Multifunction - RX chip, TX chip, Switched Amp chip, LO chain

FET- Field Effect Transistor
BJT- Bipolar Junction transistor
HEMT- High Electron mobility transistor
PHEMT- pseudo-morphic HEMT
MHEMT- metamorphic HEMT
D-HBT – Double hetero-structure bipolar transistor
CMOS- Complementary metal-oxide semi-conductor
Table 1 presents types of devices fabricated by using MMIC Technology.

Table 1: MMIC Technology

Material	FET	BJT	Diode
III-V-based	PHEMT GaAs HEMT InP MHEMT GaAs HEMT GaN	HBT GaAs D-HBT InP	Schotky GaAs
Silicon	CMOS	HBT SiGe	

C. Advantages of GaAs versus Silicon

MMICs are originally fabricated by using gallium arsenide (GaAs), a III-V compound semiconductor. MMICs are dimensionally small (from around 1 mm² to 10 mm²) and can be mass produced. GaAs has some electronic properties which are better than those of silicon. It has a higher saturated electron velocity and higher electron mobility, allowing transistors made from GaAs to function at frequencies higher than 250 GHz. Unlike silicon junctions, GaAs devices are relatively insensitive to heat due to their higher bandgap. Also, GaAs devices tend to have less noise than silicon devices especially at high frequencies which is a result of higher carrier mobility and lower resistive device parasitic. These properties recommend GaAs circuitry in mobile phones, satellite communications, microwave point-to-point links, and higher frequency radar systems. It is used in the fabrication of Gunn diodes to generate microwave. GaAs has a direct band gap, which means that it can be used to emit light efficiently. Silicon has an indirect bandgap and so is very poor at emitting light. Nonetheless, recent advances may make silicon LEDs and lasers possible. Due to its lower bandgap though, Si LEDs cannot emit visible light and rather work in IR range while GaAs LEDs function in visible red light. As a wide direct band gap material and resulting resistance to radiation damage, GaAs is an excellent material for space electronics and optical windows in high power applications.

Silicon has three major advantages over GaAs for integrated circuit manufacturer. First, silicon is a cheap material. In addition, a Si crystal has an extremely stable structure mechanically and it can be grown to very large diameter boules and can be processed with very high yields. It is also a decent thermal conductor thus enable very dense packing of transistors, all very attractive for design and manufacturing of very large ICs. The second major advantage of Si is the existence of silicon dioxide, one of the best insulators. Silicon dioxide can easily be incorporated onto silicon circuits, and such layers are adherent to the underlying Si. GaAs does not easily form such a stable adherent insulating layer and does not have stable oxide either. The third, and perhaps most important, advantage of silicon is that it possesses a much higher hole mobility. This high mobility allows the fabrication of higher-speed P-channel field effect transistors, which are required for CMOS logic. Because they lack a fast CMOS structure, GaAs logic circuits have much higher power consumption, which has made them unable to compete with silicon logic circuits. The primary advantage of Si technology is its lower fabrication cost compared with GaAs. Silicon wafer diameters are larger. Typically 8" or 12" compared with 4" or 6" for GaAs. Si Wafer costs are much lower than GaAs wafer costs, contributing to a less expensive Si IC. Other III-V technologies, such as Indium Phosphide (InP), offers better performance than GaAs in terms of gain, higher cutoff frequency, and low noise. However they are more expensive due to smaller wafer sizes and increased material fragility. Silicon Germanium (SiGe) is a Si-based compound semiconductor technology offering higher speed transistors than conventional Si devices but with similar cost advantages. Gallium Nitride (GaN) is also an option for MMICs. Because GaN transistors can operate at much higher temperatures and work at much higher voltages than GaAs transistors, they make ideal power amplifiers at microwave frequencies. In Table 2 properties of material used in MMIC technology are compared.

Table 2: Comparison of material properties

Property	Si	Si or Sapphire	GaAs	InP
Dielectric constant	11.7	11.6	12.9	14
Resistivity Ω/cm	10^3-10^5	>10^{14}	10^7-10^9	10^7
Mobility(cm^2/v-s)	700	700	4300	3000
Density(gr/ cm^3)	2.3	3.9	5.3	4.8
Saturation velocity(cm/s)	$9x10^6$	$9x10^6$	$1.3x10^7$	$1.9x10^7$

D. Semiconductor Technology

Cutoff frequency of Si CMOS MMIC devices is lower than 200GHz. Si CMOS MMIC devices are usually low power and low cost devices. Cutoff frequency of SiGe MMIC devices is lower than 200GHz. SiGe MMIC devices are used as medium power high gain devices. Cutoff frequency of InP HBT devices is lower than 400GHz. InP HBT devices are used as medium power high gain devices. Cutoff frequency of InP HEMT devices is lower than 600GHz. InP HEMT devices are used as medium power high gain devices. In Table 3 properties of MMIC technologies are compared. Fig. 6 presents a 0.15 micron PHEMT on GaAs substrate.

E. MIC Fabrication Process

MMIC Fabrication Process consist of several controlled processes in a semiconductor FAB. The process is listed in the next paragraph.

Table 3: Summary of Semiconductor technology

	Si CMOS	SiGe HBT	InP HBT	InP HEMT	GaN HEMT
Cutoff frequency	>200 GHz	>200GHz	>400 GHz	>600 GHz	>200 GHz
Published MMICs	170 GHz	245GHz	325 GHz	670 GHz	200 GHz
Output power	Low	Medium	Medium	Medium	High
Gain	Low	High	High	Low	Low
RF Noise	High	High	High	Low	Low
Yield	High	High	Medium	Low	Low
Mixed signal	Yes	Yes	Yes	No	No
1/f noise	High	Low	Low	High	High
Break down Voltage	-1V	-2V	-4V	-2V	>20V

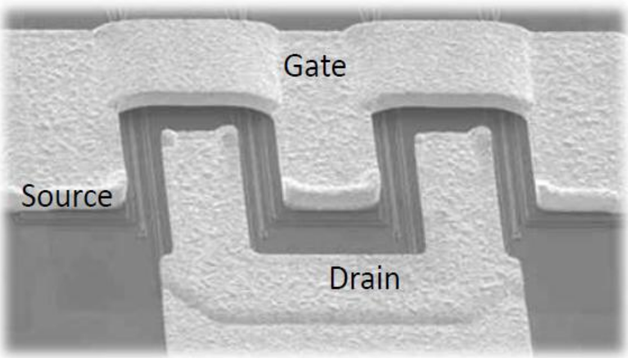

Fig. 6: 0.15 micron PHEMT on GaAs substrate

F. MMIC Fabrication Process List

Wafer fabrication

Wet cleans

Ion implantation - Dopants are embedded to create regions of increased or decreased conductivity. Selectively implant impurities. Create p or n type semiconductor Regions.

Dry etching- Selectively remove materials.

Wet Etching- Selectively remove materials chemical process.

Plasma etching- Selectively remove materials.

Thermal treatment- High temperature process to remove stress.

Rapid thermal anneal- High temperature process to remove stress.

Fu-mace anneal

Oxidation

Chemical Vapor Deposition CVD- Chemical Vapor Deposited on the wafer. Pattern defined by photo-resist. **Physical Vapor Deposition PVD-** Vapor produced by evaporation or sputtering Deposited on the wafer. Pattern defined by photo-resist.

Molecular Beam Epitaxy MBE- A beam of atoms or molecules produced in high vacuum. Selectively grow layers of materials. Pattern defined by photo-resist.

Electroplating- Electromechanical process used to add metal.

Chemical Mechanical Polish, CMP.

Wafer testing

Wafer back-grinding

Die preparation

Wafer mounting

Die cutting

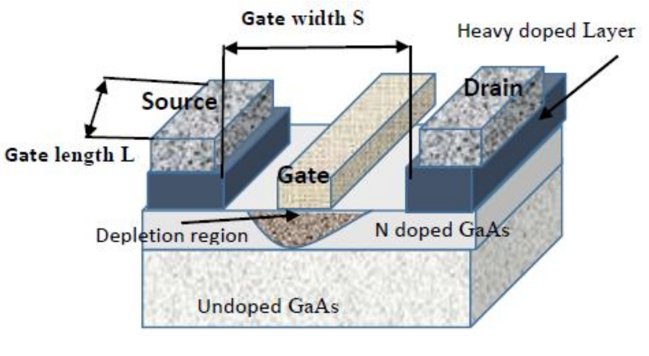

Fig. 7: MESFET cross section on GaAs substrate

In Fig. 7 MESFET cross section on GaAs substrate is shown. **Lithography** - Lithography is the process of transferring a pattern onto the wafer by selectively exposing and developing photo-resist. Photolithography consists of four steps, the order depends on whether we are etching or lifting off the unwanted material.

Contact lithography- A glass plate is used that contains the pattern for the entire wafer. It is literally led against the wafer during exposure of the photo-resist. In this case the entire wafer is patterned in one shot.

Electron-beam lithography is a form of direct-write lithography. Using E-beam lithography you can write directly to the wafer without a mask. Because an electron beam is used, rather than light, much smaller features can be resolved. Exposure can be done with light, UV light, or electron beam, depending on the accuracy needed. E beam provides much higher resolution than light, because the particles are bigger (greater momentum), the wavelength is shorter.

G. Etching versus Lift-off Removal Processes

There are two principal means of removing material, etching and lift-off. The steps for an etch-off process are:

1. Deposit material
2. Deposit photo-resist
3. Pattern (expose and develop)
4. Remove material where it is not wanted by etching

Etching can be isotropic (etching wherever we can find the material we like to etch) or anisotropic (directional, etching only where the mask allows). Etches can be dry (reactive ion etching or RIE) or wet (chemical). Etches can be very selective (only etching what we intend to etch) or non-selective (attacking a mask to the substrate). In a lift-off process, the photo-resist *forms a mold*, into which the desired material is deposited. The desired features are completed when photo-resist B under unwanted areas is dissolved, and unwanted material is "lifted off".

Lift-off process are:

- Deposit photo-resist
- Pattern
- Deposit material conductor or insulator
- Remove material where it is not wanted by lifting off

In Fig. 8 MESFET cross section on GaAs substrate is shown. In Fig. 9 a MMIC Resistor cross section is shown.

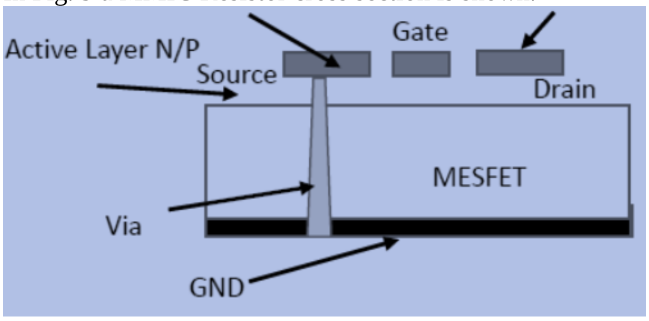

Fig. 8: MESFET cross section

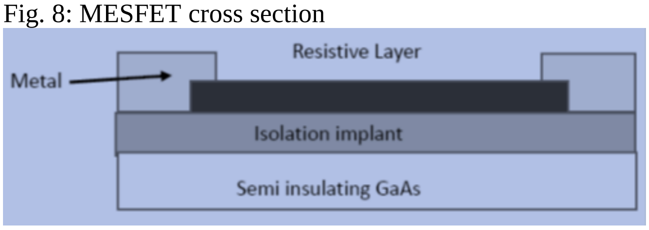

Fig. 9: Resistor cross section

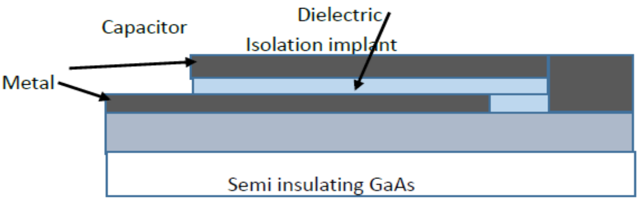

Fig. 10: Capacitor cross section

Fig. 11 presents the Ion implantation process. Fig. 12 presents the Ion etch process. Fig. 13 presents the wet etch process.

MMIC Applications

- Ka band satellite communication.
- 60GHz wireless communication.
- Automotive Radars
- Imaging in security
- Gbit WLAN

IV. MEMS TECHNOLOGY

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro-fabrication technology. These devices replace bulky actuators and sensors with micron scale equivalent that can

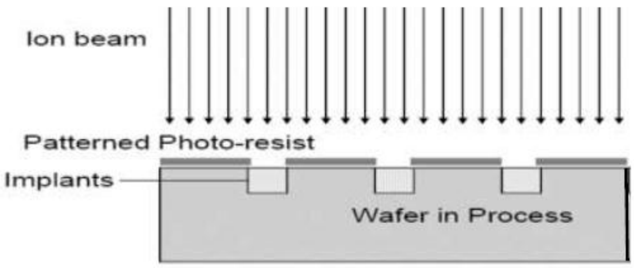

Fig. 11: Ion implantation

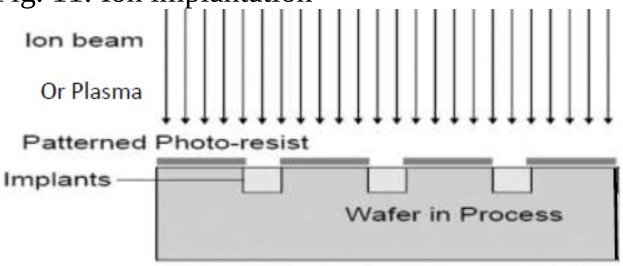

Fig. 12: Ion etch

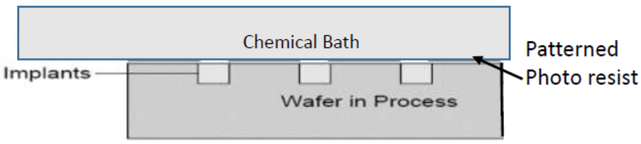

Fig. 13: Wet etch

Table 4: MMIC COST

	Si CMOS	SiGe HBT	GaAs HEMT	InP HEMT
Chip Cost($/mm^2)	0.01	0.1-0.5	1-2	10
Mask cost(M$/mask set)	1.35	0.135	0.0135	0.0135

Produce in large quantities by fabrication process used in integrated circuits in photolithography. They reduce cost, bulk, weight and power consumption while increasing performance, production volume and functionality by orders of magnitude. The electronics are fabricated using integrated circuit (IC) process sequences (e.g., CMOS, Bipolar, or BICMOS processes), the micromechanical components are fabricated using compatible "micromachining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices.

A. *MEMS Technology Advantages*

- Low insertion loss <0.1dB
- High Isolation >50dB
- Low distortion
- High Linearity
- Very High Q
- Size reduction, system-on-a-chip.
- High power handling ~40dBm
- Low power consumption
- Low cost high volume fabrication

B. *MEMS Technology Process*

Bulk micromachining fabricate mechanical structures in the substrate by using orientation dependent etching. Bulk micro-machined substrate is presented in Fig. 14.
Surface Micromachining fabricate mechanical structures above the substrate surface by using sacrificial layer.

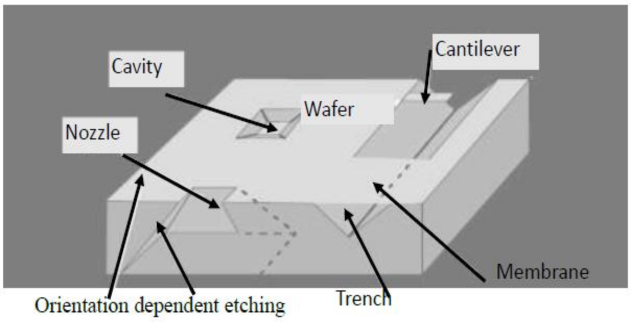

Fig. 14: Bulk micromachining

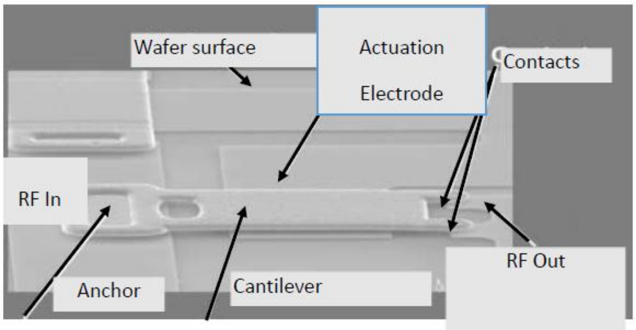

Fig. 15: Surface micromachining

Surface micro-machined substrate is presented in Fig. 15.
In Bulk micromachining process Silicon is machined using various etching processes. Surface micromachining. Surface micromachining uses layers deposited on the surface of a substrate as the structural materials ,rather than using the substrate itself. Surface micromachining technique is relatively independent of the substrate used, and therefore can be easily mixed with other fabrication techniques which modify the substrate first. An example is the fabrication of MEMS on a substrate with embedded control circuitry, in which MEMS technology is integrated with IC technology. This is being used to produce a wide variety of MEMS devices for many different applications. On the other hand, bulk micromachining is a subtractive fabrication technique, which converts the substrate, typically a single-crystal silicon,

into the mechanical parts of the MEMS device. MEMS device is first designed with a Computer Aided Design (CAD) tool. The design outcome is a layout and masks that are used to fabricate the MEMS device. In Fig. 16 MEMS fabrication process is presented. Summary of MEMS fabrication technology is listed in Table 5. In Fig. 17 the block diagram of a MEMS bolometer coupled antenna array is presented. Packaging of the device tends to be more difficult, but structures with increased heights are easier to fabricate when compared to surface micromachining. This is because of the substrates can be thicker resulting in relatively thick unsupported devices.

Table 5: Fabrication Technology

Fabrication Technology	Process
Surface Micromachining	Release and drying systems to realize free-standing microstructures
Bulk Micromachining	Dry etching systems to produce deep 2D free-form geometries with vertical sidewalls in substrates. Anisotropic wet etching systems with protection for wafer front sides during etching. Bonding and aligning systems to join wafers and perform photolithography on the stacked substrates.

C. Applications of RF MEMS Technology:

- Tunable RF MEMS Inductor
- Low loss switching matrix
- Tunable Filters
- Bolometer coupled antenna array
- Low cost W-band Detection Array

MEMS components are categorized in one of several applications. Such as:

MEMS Components

1) Sensors are a class of MEMS that are designed to sense changes and interact with their environments. These classes of MEMS include chemical, motion, inertia, thermal, RF sensors and optical sensors. Micro sensors are useful because of their small physical size, which allows them to be less invasive.

2) Actuators are a group of devices designed to provide power or stimulus to other components or MEMS devices. MEMS actuators are either electrostatically or thermally driven.

3) RF MEMS are a class of devices used to switch or transmit high frequency, RF signals. Typical devices include; metal contact switches, shunt switches, tunable capacitors, antennas, etc.

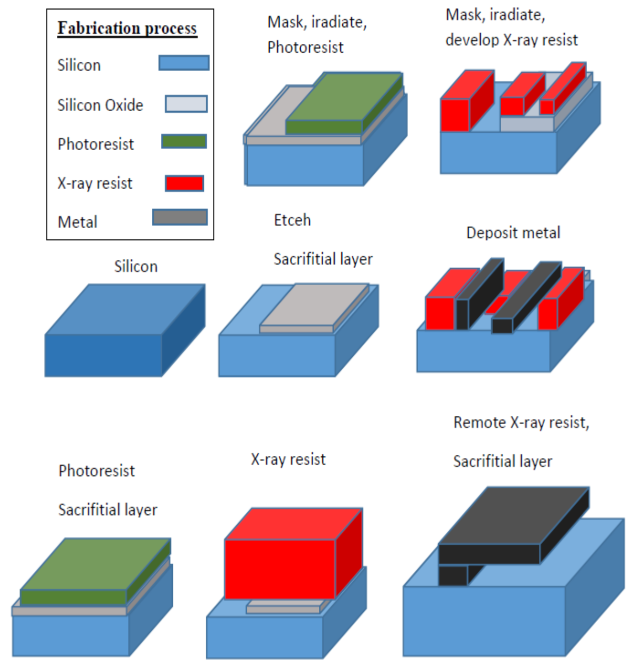

Fig. 16: MEMS Fabrication process

4) Optical MEMS are devices designed to direct, reflect, filter, and/or amplify light. These components include optical switches and reflectors.

5) Microfluidic MEMS are devices designed to interact with fluid-based environments. Devices such as pumps and valves have been designed to move, eject, and mix small volumes of fluid.

6) Bio MEMS are devices that, much like micro fluidic MEMS are designed to interact specifically with biological samples. Devices such as these are designed to interact with proteins, biological cells, medical reagents, etc. and can be used for drug delivery or other in-situ medical analysis.

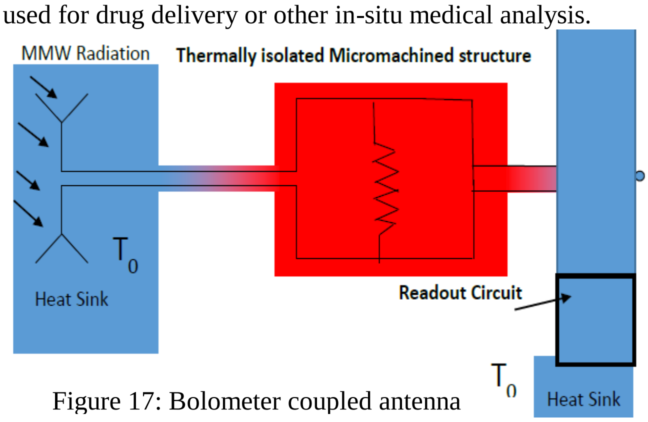

Figure 17: Bolometer coupled antenna

V. W Band Detection Array

Losses in the microstrip feed network are very high in the W band frequency range. A detection array, [4], has been designed in W band frequency range. The array concept is based on an antenna coupled to a bolometer. A direct antenna-coupling surface to a micro machined micro bridge resistor is used for heating and sensing. Analog CMOS readout circuit may be employed as a sensing channel. Fig. 17 presents a pixel block diagram. The antenna receives effective mm wave radiation. The radiation power is transmitted to a thermally isolated resistor coupled to a Ti resistor. The electrical power raises the structure temperature with a short response time. The same resistor changes its temperature and therefore its electrical resistance. The array pixel consist a patch antenna, a matching network, printed resistor and DC pads.

The printed resistor consists of Titanium lines and a Titanium resistor coupled to an isolated resistor. The operating frequency range of 92GHz to 100GHz is the best choice. In the frequency range of 30-150GHz there is a proven contrast between land, sky and high transmittance of clothes. Size and resolution considerations promote higher frequencies above 100GHz. Typical penetration of clothing at 100GHz is 1dB and 5dB to 10dB at 1THz. Design and measurement considerations promote lower frequencies. The frequency range of 100 GHz allows sufficient bandwidth when working with illumination. The frequency range of 100GHz is the best compromise. Several types of printed antennas may be employed as the array element such as bowtie dipole, patch antenna and ring resonant slot. The patch coupled to a bolometer is shown in Fig. 18.

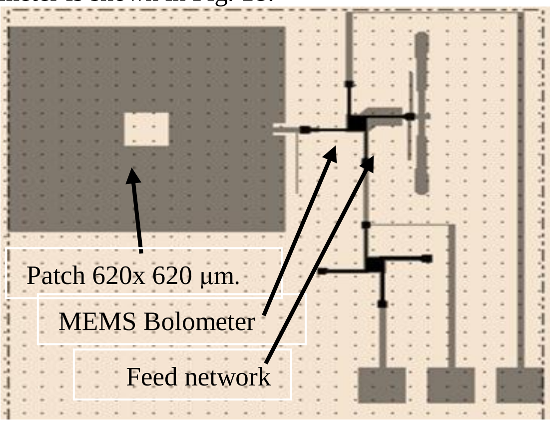

Fig. 18: Patch antenna coupled to bolometer

To minimize losses the feed line dimensions was selected as 60x10x1µm. A taper connects the 10µm width patch feed line to the 1µm width Titanium resistor line. The resistor is thermally isolated from the patch antenna by using a 3µm sacrificial layer. The patch is matched to the10µm width patch feed line by employing open circuited stubs. The patch antenna V.S.W.R is better than 2:1 in the frequency range of 92GHz to 99GHz. Ansoft HFSS software is employed to optimize the feed network dimensions. The rate of the dissipated power on the Titanium resistor is around 25% to 30%. Dissipated power on Titanium resistor is higher than the dissipated power on Platinum resistor. The rate of the dissipated power on the Platinum resistor is around 4%. The sacrificial layer thickness may be 2µm to 3µm. Fig. 19 presents the MEMS bolometer layout. The size of the patch antenna is around 620x620µm. We used a quartz substrate with thickness of 250µm. A 200GHz patch antenna have been designed on Quartz substrate with thickness of 50µm. The size of the patch antenna is around 300x300µm. The patch antenna V.SW.R is better than 2:1 at the frequency range of 200GHz to 236GHz. The detection array may be constructed from 256 to 1024 elements at 94GHz or at 220GHz. The 94GHz detection array was fabricated and measured.

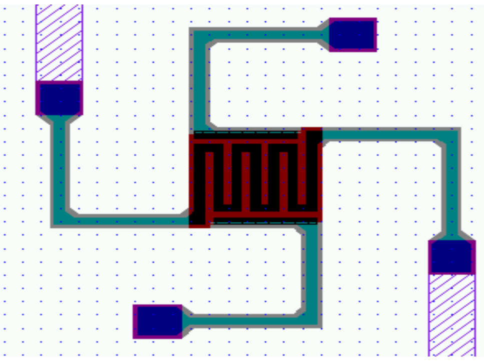

Fig. 19 MEMS Bolometer Layout

VI. 18 TO 40 GHZ INTEGRATED COMPACT SWITCHED FILTER BANK MODULE

A wideband low cost integrated 18 to 40 GHz Compact Filter Bank Module is presented. The switched filter bank consists of three channels. The filter consists of nine side coupled sections. Wide band MMIC switches are employed to select the required channel. The pass band bandwidth of each channel is around 8GHz. The Insertion Loss is around 12dB with +1dB flatness. The Rejection at +7GHz from center frequency is 40dB. The Rejection at +11GHz from center frequency is around 60dB. The Filter Bank dimensions are 20X50X10 mm.

A. DESCRIPTION OF THE FILTER BANK

The block diagram of the Filter Bank Module is shown in Fig. 20. The Filter Bank Module consists of three wideband filters. The filter consists of nine side coupled sections printed on a 5 mil alumina substrate. The filters input and output ports are connected to wide band MMIC SPDT switches via 1 to 2dB attenuators. The attenuators are employed to adjust each channel losses to the required value. The module losses are adjusted to be higher in the low frequencies and lower in the high frequencies. This feature
improve the system flatness over the frequency range. The Filters are glued to the surface of the mechanical box. The input and output switches are assembled on a covar carrier. During development it was found that the spacing between the filters and the carrier should be less than 0.03mm in order to achieve +1dB flatness and V.S.W.R better than 2:1.

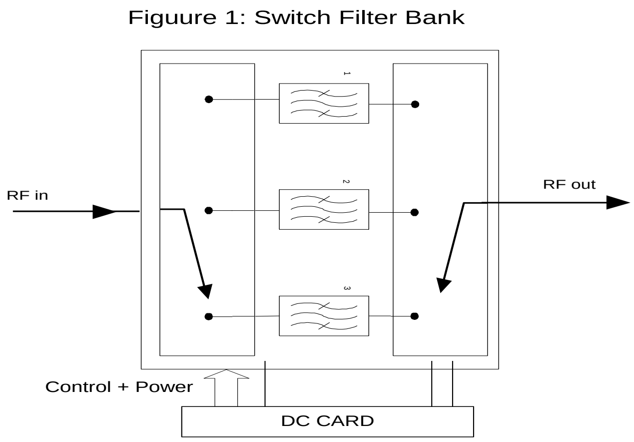

Fig. 20: 18 to 40 GHz Compact Filter Bank Module

B. Switch Filter Bank specifications

The switch filter bank specifications are listed in Table 6.
Table 6: Switch Filter Bank specifications

PARAMETER	*REQUIREMENTS*
Frequency range	18-40.1GHz
Number of channels	3
Channel Pass band	8GHz
Rejection	40dB-min.@ F0±8GHz 50dB min @ F0±11GHz
Flatness	±1.2dB max. For 4GHz
I.L: CH-1 I.L: CH-2 IL: CH-3	12-14.5dB 10.5-13.5dB 9-12dB
Switching time	100nsec
Input Power	25dBm max
VSWR	2.5 :1 max
Control	2 LVTTL lines
Supply voltages	±5V DC. Heat dissipation - 1W max
Dimension	50X20X10 mm

C. *FILTER DESIGN*

The filters have been designed by employing AWR and ADS Software. The filter consists of side coupled sections printed on a 5 mil alumina substrate. We applied optimization tools to determine the number of sections and filter configuration needed to meet the specifications. The computed results of the filters are shown in Fig. 21 to 24. The sensitivity of the design to substrate tolerances such as height and dielectric constant has been optimized. We fabricated the filter configuration that was less sensitive to production tolerances.

CH-1 FILTER

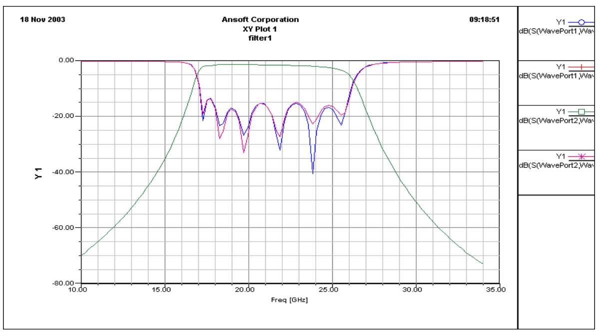

Fig. 21: S Parameters for Filter#1

CH-2 FILTER

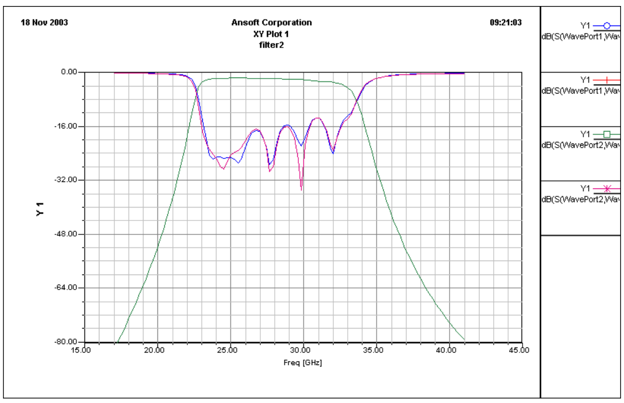

Fig. 22: S Parameters for Filter#2

CH–3 FILTER

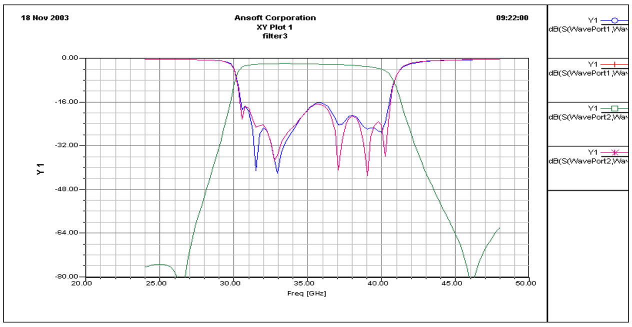

Fig. 23: S Parameters for Filter#3

Fig. 25 presents the Filter Bank computed S parameters by using ADS software. Fig. 26 presents the filter bank S12 measured results of the first unit.

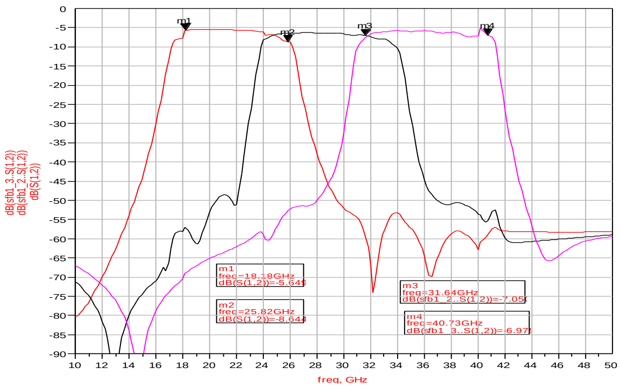

Fig. 25: Filter Bank computed S parameters

Fig. 27 is a picture of the SBF. We got a good agreement between the computed and measured results.

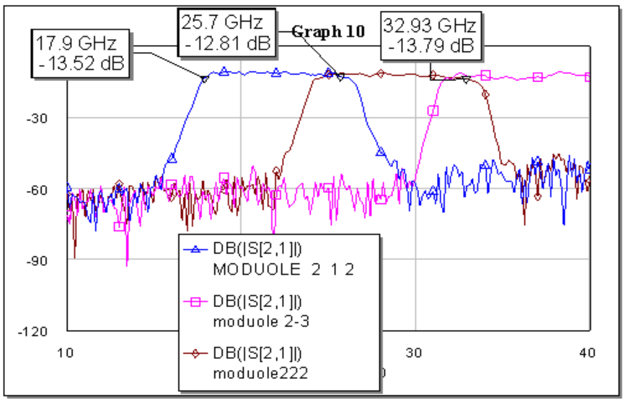

Fig. 26: Switch Filter Bank measured Results unit 1.

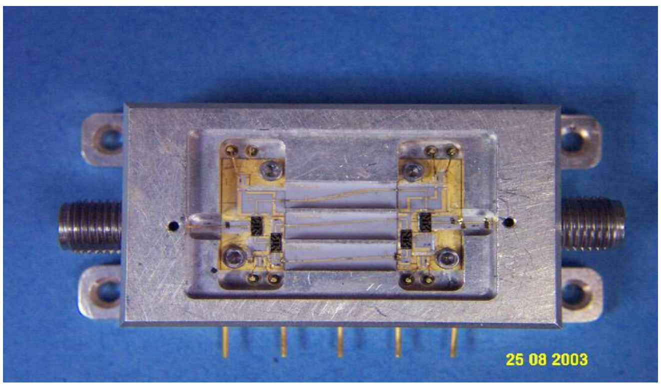

Fig. 27: SWITCH FILTER BANK PICTURE

Fig. 28 presents the measured S12 parameter of filter #2 during the production process. Fig. 29 presents the measured S12 parameter of the switch filter bank as measured in the production line. The switch filter bank losses at low frequencies are around 12dB and at the high frequencies they are around 9dB.

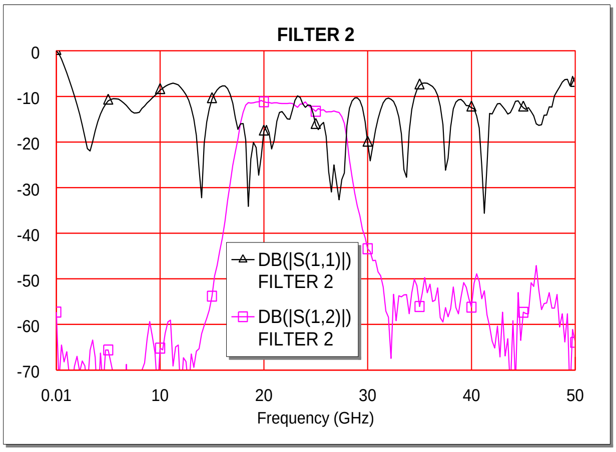

Fig. 28: Measured S Parameters for Filter#2

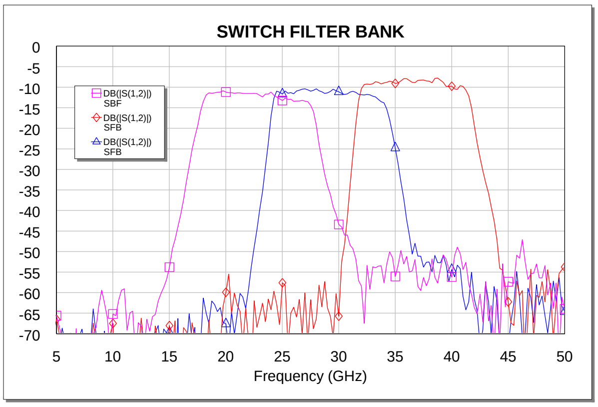

Fig. 29: SFB measured S12 results

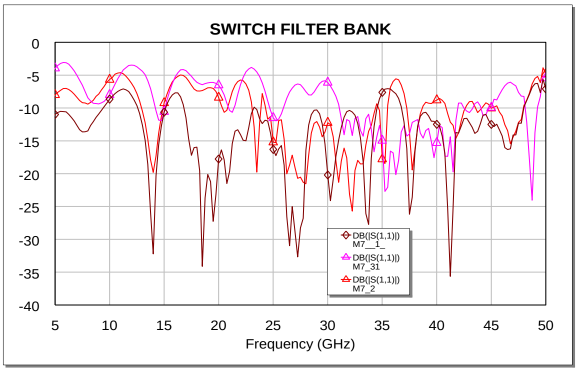

Fig. 30: SFB measured S11 results

Fig. 30 presents the measured S11 parameter of the Switch Filter bank as measured during the fabrication process.

VII. CONCLUSION

Dimension and losses of microwave systems are minimized by using Microwave Integrated Circuits, MMIC technology and MEMS technology. Dimension and losses of microwave systems are minimized by using multi-layer structure technique. Multi-layer structure technique is well-suited to thick-film print technology. Sensors, actuators and RF switches may be manufactured by using MEMS technology. Losses of MEMS components are considerably lower than MIC and MMIC RF components. MMICs are circuits in which active and passive elements are formed on the same dielectric substrate MMICs are dimensionally small and can be mass produced. MMIC components can't be tuned. MMICs and MEMS Designers goal is to comply with customer specifications in one design iteration. Several wideband modules was presented in this paper.

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