Chapter

Introductory Chapter: Ultra-Wideband Technologies

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1. Introduction

Minimization of the size, cost, and weight of the UWB RF modules and antennas is achieved by employing MMIC, MIC and MEMS technologies. However, integration of MIC, MMIC and MEMS components and modules raise technical challenges such as efficiency, accuracy, and tight tolerances. Design consideration and tolerances that can be ignored at low narrow band frequencies cannot be neglected in the design of UWB integrated RF modules. Advanced RF design software, such as ADS, CST, HFSS and AWR, should be used to achieve accurate design of UWB microwave communication devices in mm-wave frequencies. Accurate design of microwave modules and antennas is a must in development of UWB systems. It is an impossible mission to tune microwave devices in the production line.

Design of wideband UWB RF modules, filters and antennas are presented in [1–12]. Wideband RF technologies such as MIC, MIMIC and MEMS are presented in [1–7]. Wide band RF modules are crucial in the development of Direction finding, DF, systems. A fully integrated 10–40 GHz superheterodyne receiver frontend using a 40–46 GHz IF is presented in [8].

Wideband RF technologies are used to develop wideband RF modules such as frontends, active antennas and receiving and transmitting channels as presented in [1–15].

Communication and radar industry in mm wave are currently in continuous growth. The demand for wide bandwidth makes the Ka-band attractive for future commercial communication and radar industry. ADS, HFSS, AWR, and CST are system and electromagnetic software used to develop wideband RF systems, modules, and antennas, as presented in [16–19].

2. MIC and MMIC microwave and MM wave technologies

Compact low cost UWB systems may be developed and manufactured only by using miniature MMIC and MIC components.

2.1 MIC-microwave integrated circuits devices

Communication RF devices and systems consist usually of connectorized modules (such us Mixers, Amplifiers, Filters, and circulators) connected by cables. Connectorized devices are not compact and have big volume. They suffer from high losses and high weight. Volume, weight, and losses may be reduced by using Microwave Integrated Circuits, MIC technology. **Figure 1** presents a MIC Transceiver. MIC devices, standard MIC and miniature HMIC are well known types of MIC devices. Hybrid Microwave Integrated Circuit is named as HMIC device. In MIC design active and passive components are soldered or bonded to the dielectric substrate.

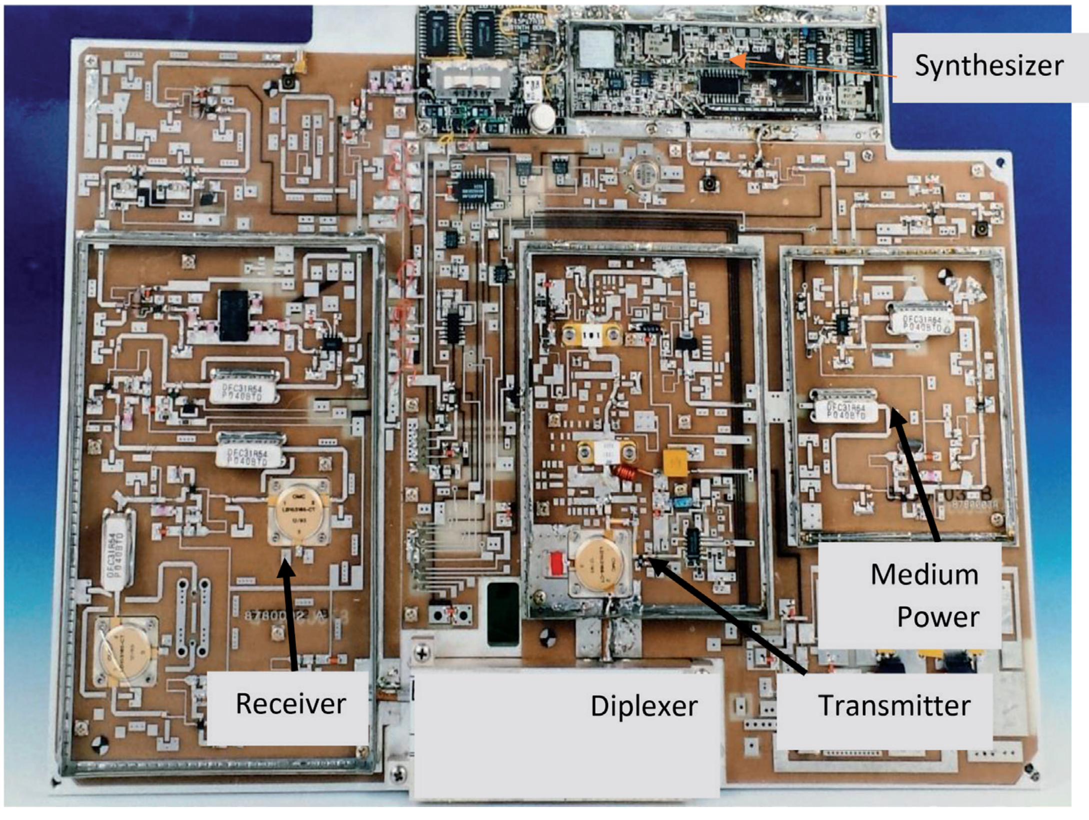

Figure 1.
MIC transceiver prototype for INMARSAT-M ground terminal.

The capacitors, resistors and other passive elements are produced by using thin or thick film technology. A single level metallization for conductors and transmission lines is used in Standard MIC technology. Multilevel process in which passive elements such as inductors, resistors, capacitors, and passive attenuators are batch deposited on the substrate in Miniature HMIC technology. Active components such as mixers, amplifiers and diodes are soldered or bonded on the substrate.

2.2 MMIC- monolithic microwave integrated circuits

MMIC are circuits in which passive and active elements are generated on the same dielectric substrate, as presented in **Figure 2**, by using a deposition scheme as epitaxy, ion implantation, sputtering, evaporation, and diffusion. The layout of the MMIC chip in **Figure 2** consists passive and active elements such as resistors, capacitors, inductors and FET, Field Effect Transistor.

2.2.1 MMIC design features

MMIC components cannot be tuned. Accurate design is crucial in the design of MMIC circuits. Accurate design may be achieved by using 3D electromagnetic software such as ADS and HFSS.

Materials used in the production of MMIC chips are SiGe, Silicon, GaAs, GaN, and InP. MMIC design is sensitive to large statistic scattering of the components, electrical parameters. Production of MMIC wafers in FAB are expensive, around $200,000 per run. Designer goal is to meet with customer specifications in the first design iteration. Compact MMIC components.

yields lower cost of the MMIC chips. **Figure 3** presents MMIC design process.

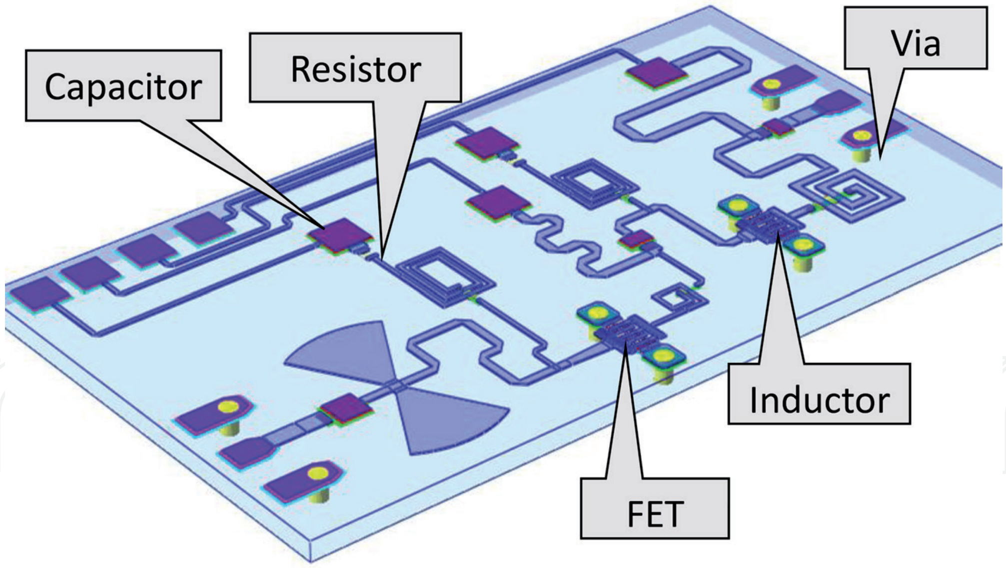

Figure 2.
Layout of MMIC chip with passive and active components.

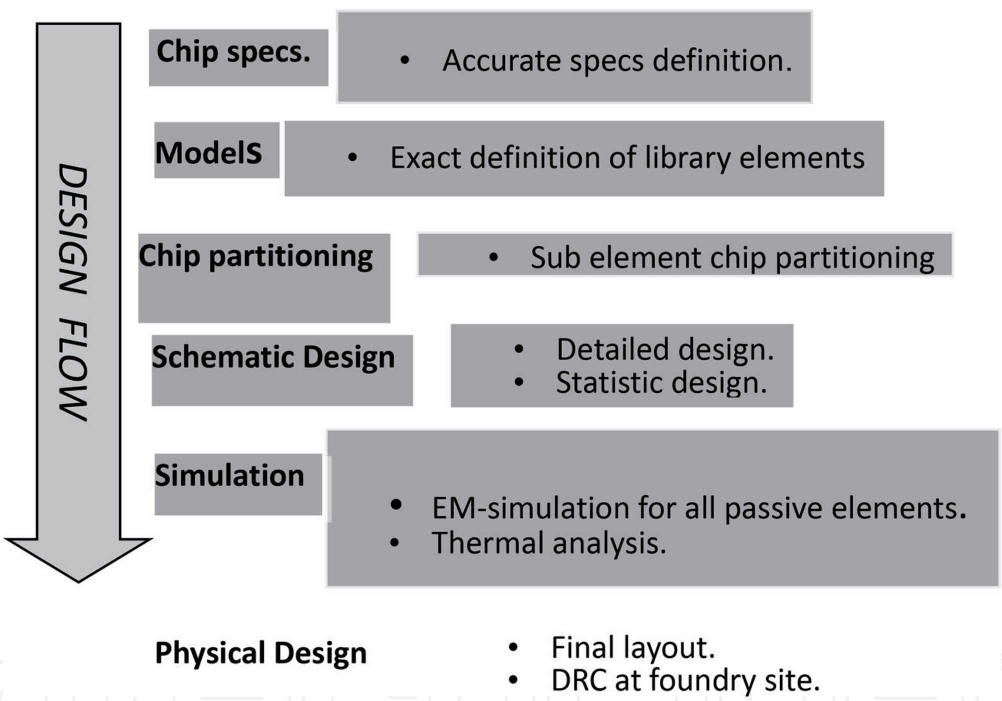

Figure 3.
MMIC design process.

2.2.2 MMIC technologies processes

- 0.25micron GaAs PHEMT amplifiers for power applications at 12GHz to 18GHz.
- 0.15micron GaAs PHEMT for applications at 18GHz to 40GHz.
- GaAs PIN process for switching applications with low power loss.
- HBT, SiGe, InP, GaN, RFMEMS, RFCMOS are new Ka band process

Wafer size may be “3, 5” or 6″. **Figure 4** presents a chip layout located on GaAs WAFER.

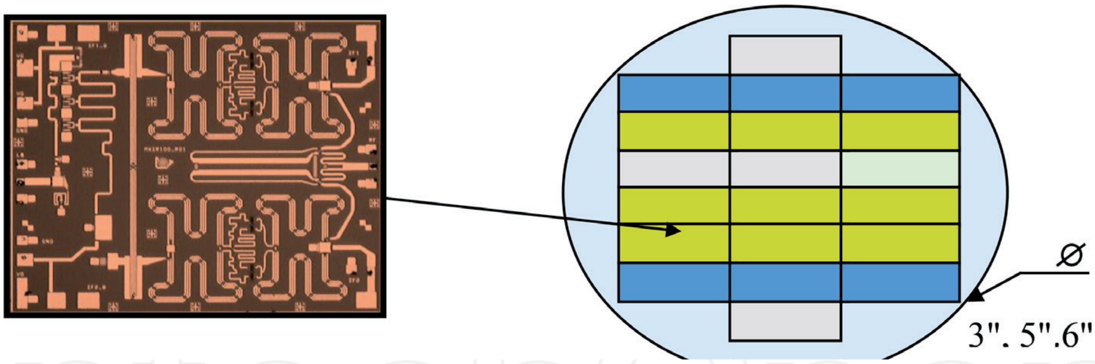

Figure 4.
GaAs WAFER layout and assembly.

2.2.3 Types of components designed using MMIC technology

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

Table 1 presents types of devices fabricated by using MMIC Technology.

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

Table 1.
Materials used in MMIC technology.

2.3 Advantages of GaAs versus silicon in MMIC design

Traditionally low frequency MMICs are produced on silicon substrate. Production costs of MMICs on silicon substrate are cheaper. High frequency MMICs are produced on gallium arsenide (GaAs), a III-V compound semiconductor. MMICs are compact and have low volume and area (from around 1 mm^2 to 10 mm^2). MMICs can be produced in low-cost mass production. The electronic properties of GaAs are significantly better than those of silicon. GaAs has a higher electron mobility and higher saturated electron velocity than silicon. These properties allow transistors produced on GaAs to operate at frequencies higher than 0.3THz. In comparison to silicon devices, GaAs chips are less sensitive to heat because their higher bandgap. Noise of GaAs modules at high frequencies is lower considerably than the noise of silicon modules because of lower resistive device parasitic and higher carrier mobility. These features make GaAs chips and modules attractive to smartphones, cellular phones, medical communication systems, radars, and high frequency phased arrays. Gunn diodes are produced on GaAs substrate to generate RF signals. GaAs devices can be used to emit light efficiently since they have a direct band gap. Silicon devices are very poor at emitting light due to their indirect bandgap. Recent advances may make silicon lasers and LEDs possible. Si LEDs cannot emit visible light and rather work in IR range due to theirs lower bandgap. However, GaAs LEDs may function in visible red light. GaAs substrate is a good choice in high power applications for space electronics devices and optical applications. Silicon is a cheaper substrate than GaAs substrate. Silicon crystal has a significantly mechanically stable structure. Silicon can be grown to very large diameter units. Silicon modules have very high yields. Silicon modules are very attractive for design and production of very large ICs due to good thermal properties of silicon which enable very dense packing of transistors. Silicon dioxide is one of the best insulators, this is a major advantage of Silicon. Silicon dioxide can easily be used in silicon devices. Silicon dioxide layers are adherent to the underlying Silicon layer. GaAs does not have does not have stable oxide does not form a stable adherent insulating layer. An important advantage of silicon over GaAs is the higher hole mobility of silicon which allows the production of higher-speed P-channel field effect transistors. These transistors are required for CMOS logic. GaAs transistors lack a fast CMOS structure. So, GaAs logic circuits have much higher power consumption, GaAs logic cannot compete with silicon logic modules. Silicon technology has lower production cost compared with GaAs devices, contributing to a cheaper Silicon IC. Silicon wafer diameters are typically, 20 cm or 28 cm. GaAs wafer diameters are 10 cm to 15 cm. Other, Indium Phosphide (InP) III-V technologies, offers better properties than GaAs in terms of higher cutoff frequency, gain, and noise figure. InP devices are more expensive than silicon and GaAs modules. InP wafer sizes are smaller than GaAs wafers and are more fragile. Silicon Germanium technology offers higher speed transistors than conventional Silicon devices with similar cost expenses. Gallium Nitride, GaN, is used to produce power amplifiers MMICs. GaN transistors can work at much higher voltages and function at much higher temperatures than GaAs transistors, they are used to produce power amplifiers at high frequencies. Properties of dielectric substrates used in MMIC technology are given in **Table 2**.

2.3.1 Semiconductor in MMIC devices

Si CMOS MMIC modules are low power and low-cost devices. Si CMOS MMIC modules may operate in frequencies lower than 0.2THz. SiGe MMIC devices are used as medium power high gain devices. SiGe MMIC modules may operate in frequencies lower than 0.2THz. InP HBTs modules may operate in frequencies lower

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

Table 2.
Comparison of material properties in MMIC technology.

than 0.4THz. InP HBT modules are used as high frequency medium power high gain devices. InP HEMT modules may operate in frequencies lower than 0.6THz. InP HEMT devices are used as high frequency medium power high gain devices. Properties of MMIC technologies are presented in **Table 3**. PHEMT, 0.15micron, on GaAs substrate is shown in **Figure 5**.

GaN HEMT	InP HEMT	InP HBT	SiGe HBT	Si CMOS	
<0.2THz	<600GHz	<0.4THz	<0.2THz	<0.2THz	High frequency
<0.2THz	<0.68THz	<0.33THz	<0.25THz	<0.2THz	MMICs
High	Medium	Medium	Medium	Low	P-Out
Low	Low	High	High	Low	Gain
Low	Low	High	High	High	Noise
Low	Low	Medium	High	High	Yield
No	No	Yes	Yes	Yes	Mixed signal
High	High	Low	Low	High	1/f noise
>20 V	-2 V	-4 V	-2 V	-1 V	Breakdown Voltage

Table 3.
Summary of semiconductor for MMIC technology.

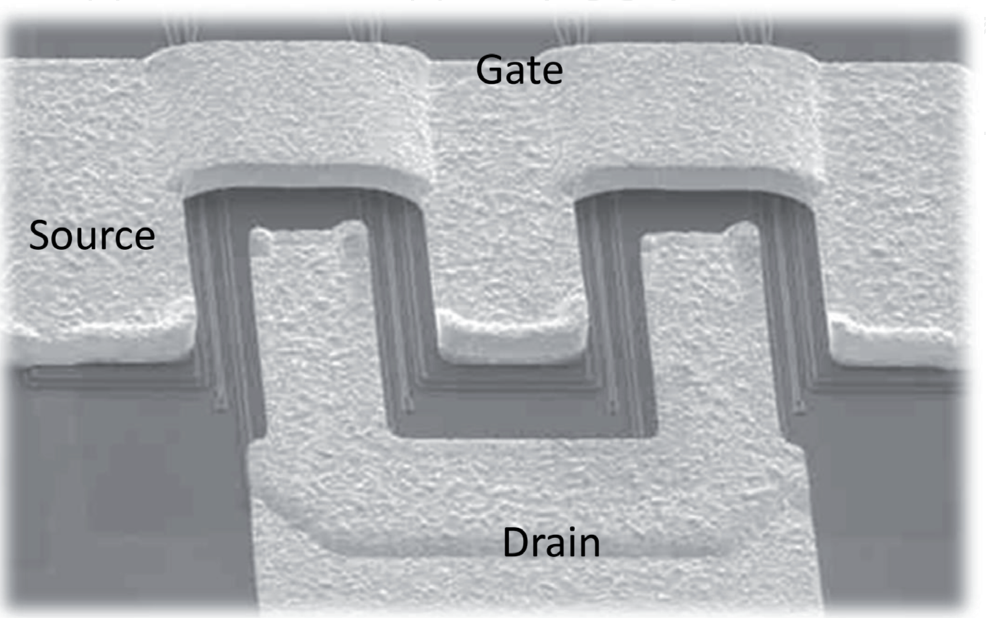

Figure 5.
Photo of 0.15micron PHEMT MMIC on GaAs substrate.

2.4 Generation of microwave signals in microwave and mm wave

RF Signals can be excited in vacuum-tube based devices and in solid-state oscillators. Solid state modules are produced on semiconductors such as silicon, SiGe, gallium arsenide, GaN and include bipolar junction transistors (BJTs), field-effect transistors (FETs), Gunn diodes, and IMPATT diodes. RF variations of BJTs include the heterojunction bipolar transistor (HBT), and RF variants of FETs include the MESFET, the HEMT, and LDMOS transistor. RF waves can be generated and processed using MIC circuits and MMICs. Traditionally these modules are produced on gallium arsenide wafers. However, silicon germanium and heavy-dope silicon are recently used to produce high power modules. Vacuum tube high power modules operate on the ballistic motion of electrons in a vacuum under the influence of controlling magnetic or electric fields. These devices work in the density modulated mode, rather than the current modulated mode. They work on clumps of electrons flying ballistically through them. These devices include traveling wave tube, klystron, magnetron, and gyrotron.

2.5 MMIC modules and applications

A wide band Ka band power Amplifier is shown in **Figure 6**. The input power is divided by using a splitter. The microwave signal is amplified by power amplifiers and combined by a power combiner to get the desired output power.

A Ka Band wideband non reflective MMIC Pin diode SPDT is shown in **Figure** 7. MMIC process cost per the MMIC area is given in **Table 4**.

MMIC Applications

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

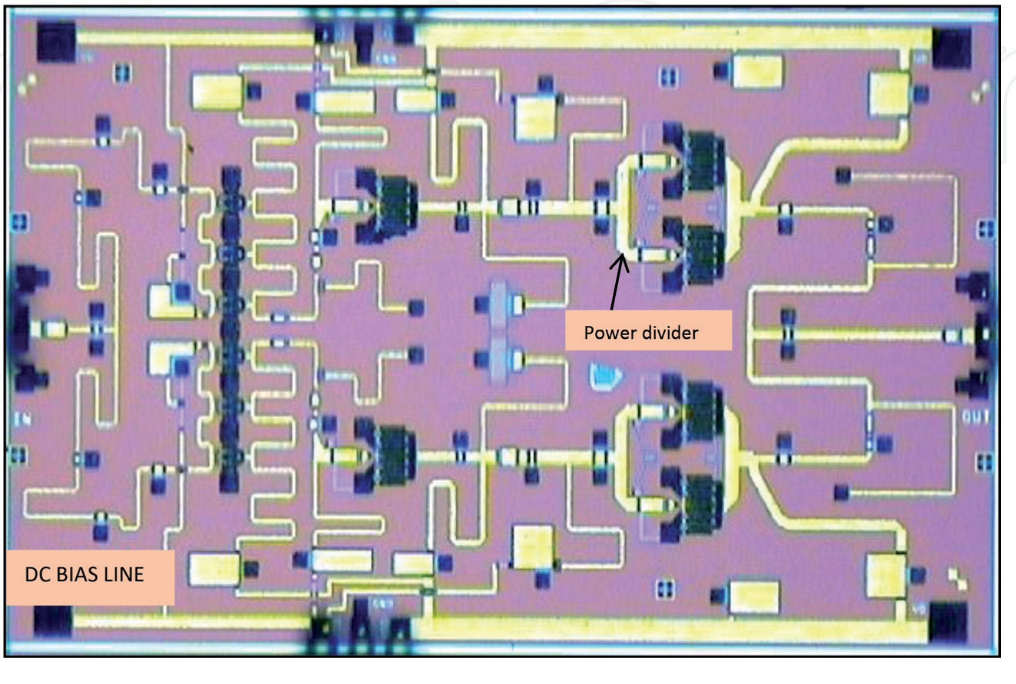

Figure 6.
Wide band MMIC mm-wave power amplifier.

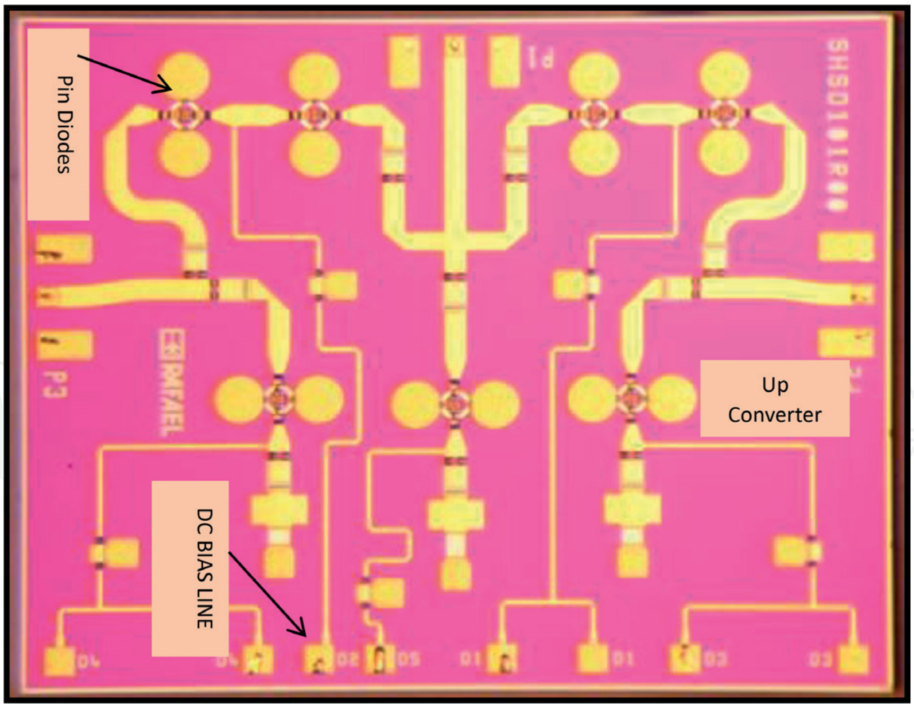

Figure 7.
Wideband Ka band non reflective SPDT.

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

Table 4.
MMIC COST.

3. MEMS technology

Micro-Electro-Mechanical Systems (MEMS) technology integrate sensors, actuators, mechanical elements, and electronics on the same silicon substrate using microfabrication technology. MEMS modules replace connectorized devices, actuators, sensors, and antennas with micron scale similar devices that can be produced in mass production by a production process using integrated circuits and photolithography technology. MEMS devices reduce size, cost, weight, and power consumption while improving properties, production cost and yield, volume, and functionality significantly. The dimensions of MEMS modules may vary from several millimeters to around one micron. MEMS modules may vary from very simple structures to structures with moving elements. There are complex MEMS electromechanical systems with several moving elements controlled by integrated microelectronics. During the last thirty years MEMS designers, developers and researchers have produced an extremely large number of MEMS sensors for several sensing applications. For example, pressure sensing, heartbeat, temperature sensing, inertial forces, chemical species, magnetic fields, radiation detection and movement detection. Usually, these MEMS sensors have better performances exceeding those of conventional sensors and devices. The electronics components are produced using IC process. The micromechanical components are produced by using compatible "micromachining" processes. These processes, by using masks, etch away parts of the silicon wafer or add new structural layers to form the electromechanical and mechanical modules.

The real potential of MEMS may be fulfilled when these miniaturized sensors, actuators, and other components can all be merged onto a common silicon substrate along with integrated circuits, microelectronic ICs. The electronic components are fabricated using integrated circuit (IC) process sequences (such as 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.

3.1 MEMS technology features and advantages

- Insertion loss lower than <0.1 dB
- Isolation lower than -50 dB
- High Linearity compared to conventional devices
- High Q compared to conventional devices
- Low volume and compact
- High power handling compared to conventional devices
- Low power consumption compared to conventional devices
- Low-cost and high-volume production compared to conventional devices

3.2 MEMS technology process

Bulk micromachining produces mechanical structures in the silicon substrate by using etching masks. Bulk micro-machined module is shown in **Figure 8**.

Surface Micromachining produce mechanical structures above the substrate surface by using sacrificial layer. Surface micro-machined module is presented in **Figure 9**. In Bulk micromachining technology silicon is machined using etching processes. Surface micromachining uses layers deposition on the substrate to produce a structural layer.

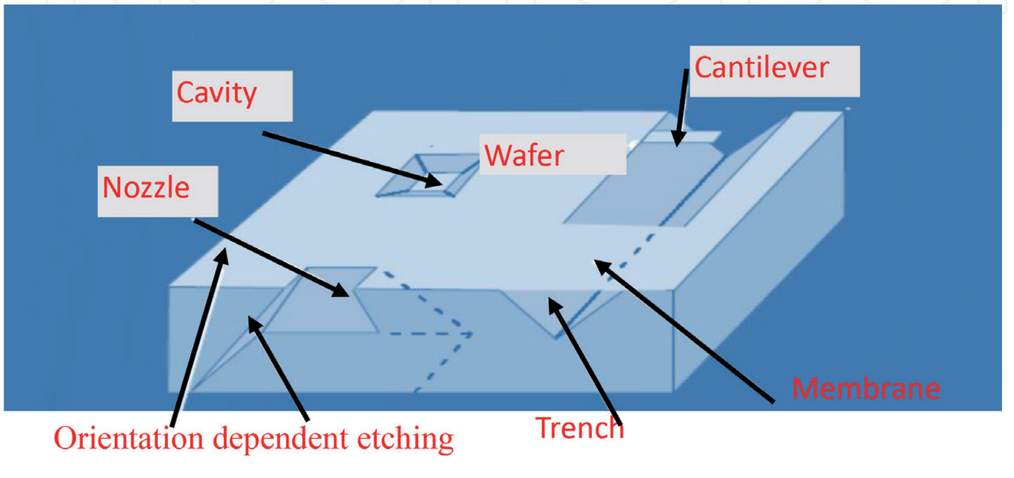

Figure 8.
MEMS bulk micromachining technology.

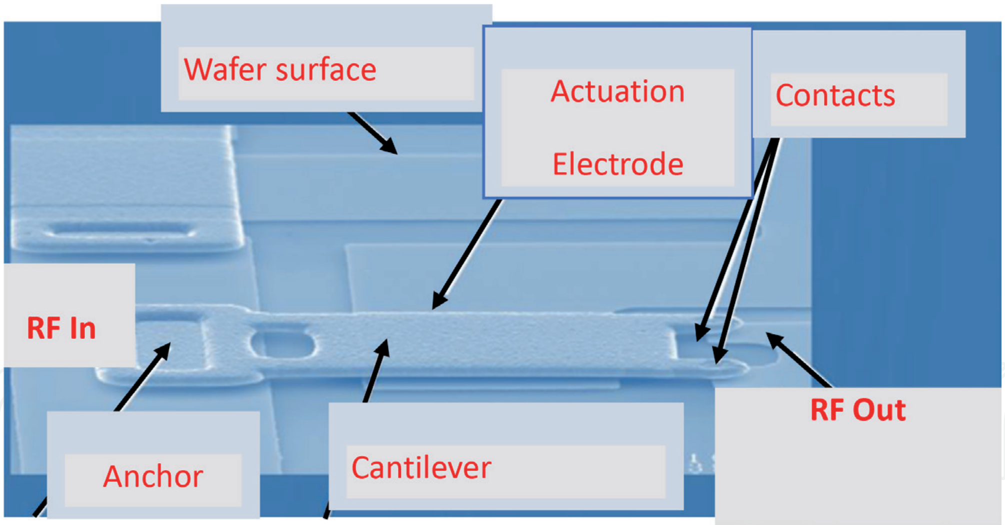

Figure 9.
MEMS surface micromachining technology.

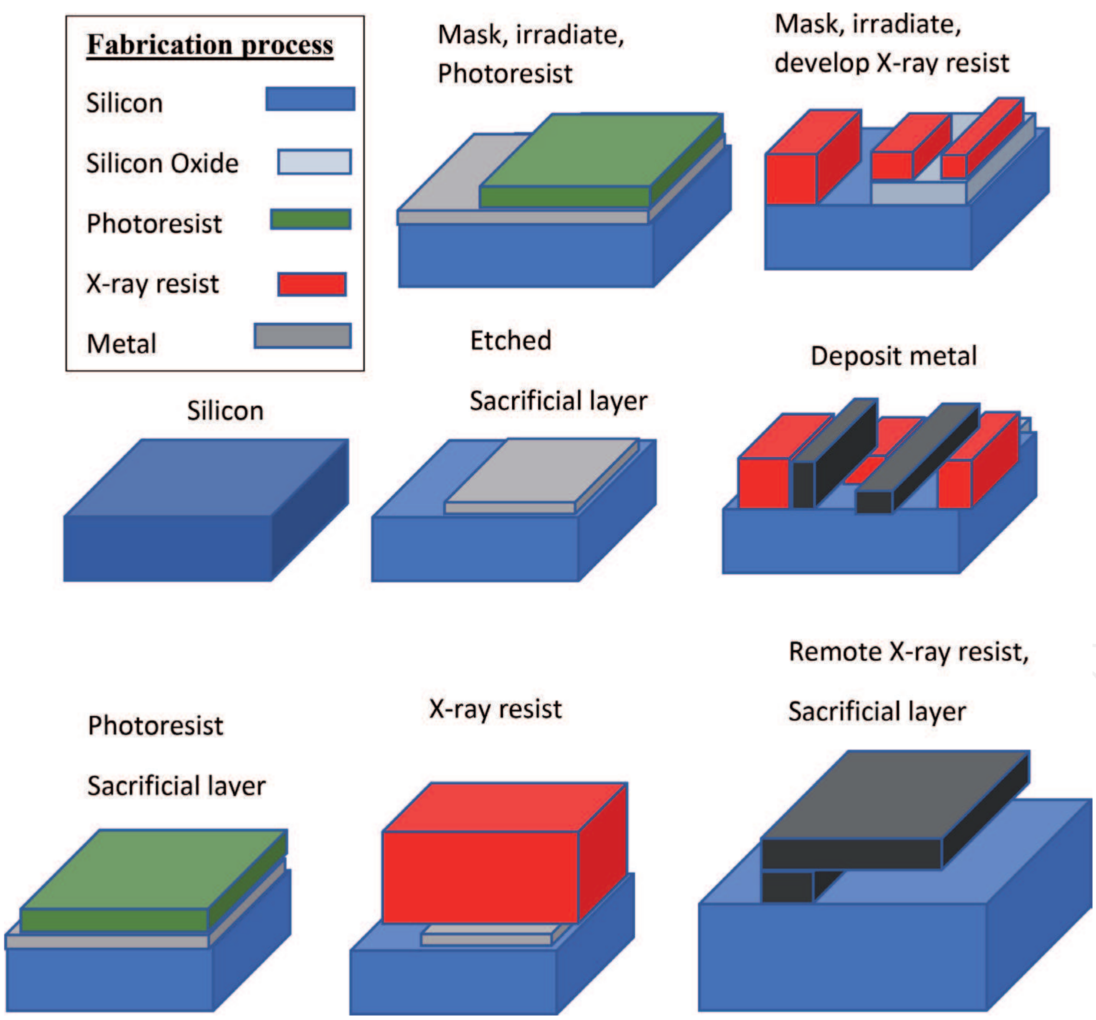

Figure 10.
MEMS *fabrication process.*

Surface micromachining process does not depend on the substrate used. It can be part of other production processes that modify the substrate. For example, fabrication of MEMS on a substrate with embedded control devices, in which MEMS process is integrated with integrated circuit technology.

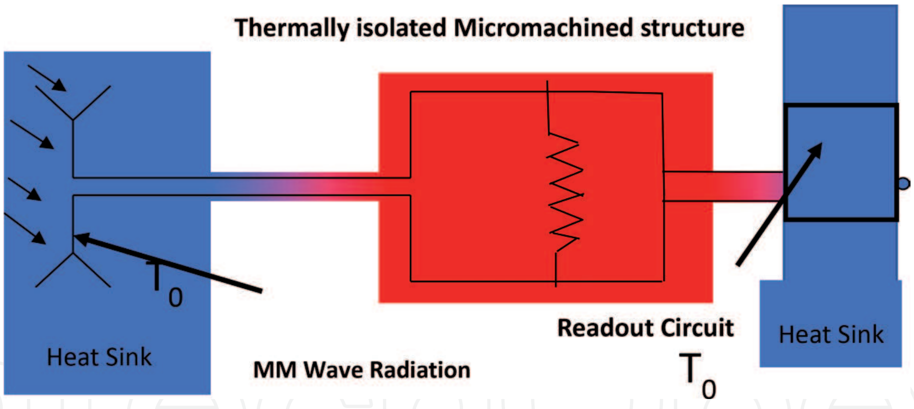

Figure 11.
MEMS bolometer coupled antenna array.

This process is used to manufacture a wide spectrum of MEMS modules for several applications. Bulk micromachining is a subtractive fabrication process, that converts the substrate, into the mechanical parts of the MEMS module. MEMS modules can be designed by using electromagnetic software such as ADS, HFSS, and CST. The design outcomes layers masks, layout that are used to produce the MEMS module. MEMS production process is shown in **Figure 10**. In **Figure 11** the block diagram of a MEMS bolometer coupled antenna array is presented. Packaging of MEMS modules may be more complicated. However, higher devices are easier to produce when compared to surface micromachining. Applications of RF MEMS technology:

- Tunable microwave MEMS passive elements such as inductors and filters
- MEMS Switching matrix with low loss
- MEMS antenna arrays coupled to bolometer for detection arrays
- MEMS 90GHz Detection Arrays

3.3 MEMS components

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

1. **MEMS The goal of MEMS sensors** is to sense changes and interact with the environments. MEMS sensors include sensors that detect change in temperature, sensors that detect chemical changes, movement sensors, optical sensors, radiation sensors and inertia sensors. MEMS sensors are useful due to their low-cost and small volume.

2. **Microwave MEMS** are modules used to transmit microwave signals, to switch or to filter RF signals. **Microwave MEMS** include tunable capacitors, switches, filters, antennas, and phase shifters.

3. **Optical MEMS** are compact modules that amplify, direct, reflect, and filter light such as optical reflectors and switches.

4. Thermal or electrostatic actuators provide power to other components or devices.

5. **Biological MEMS** are modules that, interact with biological tissue. These modules interact with biological cells, medical reagents, proteins, and other

biological tissues. These devices may be employed for drug delivery or other medical missions.

6. **Microfluidic MEMS** are low-cost modules that interact with fluid environments. Modules such as pumps and valves. Devices that move, mix, and eject and are compact.

4. Computer aided design, CAD, commercial software

In the last decade, several electromagnetic commercial software was developed, see [16–19]. The most popular software that are used in the design and development of wearable systems and antennas will be presented in this section.

4.1 High frequency structure simulator, HFSS, software

ANSYS HFSS RF simulation software is a full wave electromagnetic software. HFSS is used to simulate RF modules and antennas [17]. For example, printed antennas, waveguides and other transmission lines, connectors, antenna arrays, phased arrays, microwave devices, digital circuits, filters, MIC and MMIC packages and other RF devices. ANSYS HFSS is used to develop RF, high-speed RF systems, seekers, radar systems, microwave devices, RF satellites modules, internet of things (IoT) products and other high-speed microwave and digital devices. For more information see, https://www.ansys.com/products/electronics/ansys-hfss.

HFSS employs several solvers to give the RF engineer deep insight into all the 3D electromagnetic problems. Through integration with ANSYS thermal, structural and fluid dynamics tools, HFSS provides a multi-physics analysis of RF products, ensuring their thermal and structural reliability. The ANSYS HFSS simulation suite consists of a comprehensive set of solvers to address diverse electromagnetic problems. Its automatic adaptive mesh refinement lets the designer to focus on the design instead of spending time determining and creating the best mesh.

4.1.1 HFSS electromagnetic solvers

ANSYS HFSS employs full wave 3D finite element method, momentum (MoM) analysis and the SBR ultra-large-scale asymptotic method of shooting and bouncing rays with advanced diffraction and creeping wave physics for enhanced accuracy (SBR+). The ANSYS HFSS software package has the following solvers to solve RF problems:

HFSS Solvers

- Solver in the frequency domain
- Solver in the time domain
- Solver using integral equations
- Solver that uses hybrid technologies

HFSS SBR+

- Solver that uses physical optics
- Solver that uses shooting and bouncing Ray

- Solver that uses physical theory of diffraction
- Solver that uses Creeping Wave
- Solver that uses uniform theory of diffraction

Each HFSS may solve a specific module, environment, RF devices or application.

HFSS RF Solver Features

- Communication system link budget calculations
- Wireless propagation solver
- Microwave and antennas solver
- Automated diagnostics simulation
- Microwave component libraries
- Multi-fidelity RF models
- Coupling models and analysis

Types of Circuit Simulation

- Linear circuit analysis
- DC circuit analysis and simulation
- Transient circuit analysis and simulation
- RF system multitone harmonic balance analysis

For more information see, https://www.ansys.com/products/electronics/ansys-hfss.

4.2 Advance design system, ADS

ADS is an electronic design automation software system. It offers complete design integration to designers of products such as cellular and portable phones, pagers, wireless networks, and radar and satellite communications systems [16].

ADS support communication system and RF design engineers to develop all types of RF designs, from RF and microwave modules and printed antennas to integrated MMICs for communication, medical, IOT and aerospace defense applications.

With a complete set of simulation technologies ranging from frequency and time domain circuit simulation to electromagnetic field simulation. ADS let designers fully characterize and optimize designs. Such as Harmonic Balance, Circuit Envelope, Transient Convolution, Ptolemy, X-parameter, Momentum, and 3D EM simulators (including both FEM and FDTD solvers).

ADS Simulation and Design Major Features

- Development and design of communication and RF systems
- Analysis results presentation, S parameters data and plots
- S-parameters simulation, DC, and small signal AC simulation
- Simulation of RF devices, modules, and systems
- Yield statistical simulation including components tolerances simulation to get accurate design
- Optimization of component parameters to get accurate design and high yield
- Development and design of several types of filters
- Development and design of passive devices, S-parameters simulation
- Developer of customized design guides
- ADS software libraries such as microwave component and systems, passive and active components
- Design and development of MIC and MMIC modules
- Electromagnetic simulation, radiation simulation
  ADS Suite Features
- **Design tools** - Schematic graphical friendly user interface. Circuit schematic entry and simulation setup.
- **Computation results presentation** – Display graphically and tables of analysis results.
- **Connection Manager** – Allow to read data from data files downloads. Control measurement instruments.
  Simulators
- Frequency-domain linear RF modules simulator.
- Optimization simulation, Yield simulation, Yield Optimization, experiments design, and Presentation of Statistical yield histograms.
- **Electromagnetic Momentum Simulator** - Electromagnetic Momentum, EM, Simulator is a frequency domain simulation CAD tool. EM combines layout editing tools with electromagnetic simulation and S-parameters simulation to get accurate RF design. EM analysis suite includes schematic tools, simulation results presentation, EM simulator, and multilayer layout editor.
- **Microwave and Communication System Simulation** – Modular analysis of microwave and communication systems. Analysis of each unit and component in the system.

- **Models of Passive Components** - Models for capacitors, inductors, transformers, couplers, conductors, vias, and crystals.
- **Models for Multilayer Design** - Coupled lines models for multilayer modules such as MIC PCB, MMIC modules, and devices packaging.
- **Models for Active Microwave Devices** – Amplifiers, modulators and demodulators, mixers, and switches.
- **Design Guide for Passive Devices** - Simulation and optimization of microstrip circuits such as couplers, branch-line couples, dividers, coupled line filters, microstrip matching circuits and lumped-element circuits.
- **Passive Filters Simulator** - Simulation and optimization of passive filters.

4.2.1 FEM simulator

The FEM simulator has a full-wave three dimensions electromagnetic simulation capabilities, based on the Finite Element Method (FEM). The RF-Pro User Interface (UI), that comes with this FEM element, makes setting up RF circuit co-simulation in Advanced Design System (ADS) fast with no errors for the design of multi-technology RF modules that integrate RFIC, MMIC, package and PCB. It also automates the extraction of nets and components for EM simulation without modifying the layout. The FEM simulator enable to simulate 3D structures such as connectors, wire-bonds and packaging with circuit and system components. It is important especially for RF module designs where 3D interconnects and packaging must be simulated along with the circuit. For more details see in, https://www.keysight.com/en/pc-1297113/advanced-design-system-ads?nid=-34346.0&cc=IL&lc=eng.

The frequency domain simulation can be used in the Electromagnetic Professional (EM-Pro) software, in the 3D EM platform and in ADS.

4.3 CST software

CST is a **3D** electromagnetic **simulation** software for developing, designing, analyzing, and optimizing RF components and systems [18]. Information about CST is presented in, https://www.3ds.com/products-services/simulia/products/cst-studio-suite/.

CST Electromagnetic field solvers gives engineers the flexibility to RF systems that consists of many components and modules. CST SIMULA software allows electromagnetic simulation to accompany the design process from the earliest design stages to the final development milestone. CST EM analysis include design of couplers, dividers, antennas, filters, MEMS, electromagnetic compatibility simulation (EMC/EMI), simulation near human body, and thermal effects in transmitters. SAM a System Assembly and Modeling tool provides simple environment simulation software RF systems. The SAM suite may be employed for simulating, analyzing, and optimizing RF devices that consists of several components. The simulation products are physical quantities such as voltages, currents, fields, and S-parameters. SAM helps designers to compare the results of different solvers within one analysis project and perform post-processing simulation. For example, using the results of electromagnetic simulation to analyze thermal effects, then structural thermal effects, and other EM simulation to analyze detuning. This analysis process helps to reduce the calculation effort required to analyze a complex device accurately. The

CST software is a 3D modeling schematic layout tool, with electromagnetic solvers and post-processing simulations.

CST Solvers

- Transient solver
- TLM solver
- Frequency domain solver
- Eigenmode solver
- Resonant solver
- Integral Equation Solver
- Asymptotic Solver

CST Products

- CST EM analysis is used to design several RF devices and systems. Such as couplers, dividers, antennas, filters, MEMS, electromagnetic compatibility simulation (EMC/EMI), simulation near human body, SAR problems, and thermal effects in transmitters.
- CST Simulation products include static, stationary, high and low frequency analysis of RF systems, and components with movement of charged particles.
- CST software is used to analyze multilayer structures, transmission lines, EMC design, small antennas, antenna arrays, packaging, LTCC devices, inductors, capacitors, waveguide devices, actuators, plasma sources, optical devices, sensors, recording units, and electromagnetic brakes.

4.4 Microwave office, AWR

Microwave Office design suite provides a flexible RF/microwave design tool [19].

Built on AWR high-frequency design platform with its open design environment and advanced unified data model. AWR operates with Visual System Simulator, VSS, system design, AXIEM and Analyst EM simulation software. The NI AWR Design suite provide a complete microwave devices solver, system solver, and EM simulation.

Microwave Office AXIEM electromagnetic (EM) software is an EM analysis.

The AXIEM product was developed specifically for three-dimensional (3D) planar applications such as RF PCBs and modules, LTCC, MMIC, and RFIC designs.

The APLAC simulator offers multi-level analyses which includes:

- DC operation point
- Linear frequency domain
- Time domain
- Harmonic balance

- Phase noise
- Linear/non-linear noise including AC noise contributors, temperature
- Yield predictions and optimization

More information can be found in https://www.awr.com/serve/microwave-office-brochure-1.

AWR provide accurate simulation tool and offers RF devices analysis and optimization. AWR provides a linear and nonlinear time and frequency domain simulation needed to characterize and optimize RF modules. AWR major features are listed below.

- **Microwave and Communication System Simulation** – Modular analysis of microwave and communication systems. Analysis of each unit and component in the system.
- **Models of Passive Components** - Models for capacitors, inductors, transformers, couplers, conductors, and SMT components.
- **Models for Multilayer Design** - Multilayer modules such as MIC PCB, MMIC modules, and devices packaging.
- **Active Microwave Devices Simulation** – Linear and nonlinear simulation, Amplifiers, modulators and demodulators, mixers, and switches.
- **Passive Devices** Simulation - Simulation and optimization of microstrip circuits such as couplers, branch-line couples, dividers, coupled line filters, microstrip matching circuits and lumped-element circuits.
- **Passive Filters Simulator** - Simulation and optimization of passive filters.

AWR Capabilities– The AWR user interface provides project management and design tools for RF devices. The designers can build a device layout model from the software component library. The library supports tuning and optimization simulation.

- **Computation results presentation** – Display graphically and tables of analysis results.

Simulation APLAC – This robust harmonic-balance (HB) simulator provides linear and nonlinear circuit analysis with powerful multi-rate HB, transient-assisted HB, and time variant (circuit envelope) analysis, supporting large-scale and highly nonlinear RF/microwave circuits.

Planar EM – AXIEM provides accurate characterization, simulation, optimization of passive devices, planar transmission lines, printed antennas, and printed arrays.

3D EM – 3D finite element solver provides fast and accurate electromagnetic analysis of multilayer elements such as vias and bonds. The high frequency full wave analysis helps in developing RF modules from the beginning of the design up to the final electromagnetic verification.

AWR for MMIC Modules Design

- Linear and nonlinear MMIC Modules design with frequency-domain and time-domain simulation.

- MMIC module layout and production files and masks, GDSII export.
- MMIC module electromagnetic simulation and optimization from layout or schematic using commercial electromagnetic solvers.
- MMIC module design and layout rule check versus schematic.

5. Ultra-wideband compact integrated modules

UWB integrated modules of 18 to 40GHz Direction Finding system are shown in **Figures 12** and **13**. A photo of a compact UWB frontend is shown in **Figure 12**. The frontend module consists of a limiter and a wideband 18 to 40GHz LNA. The low noise amplifier LMA406 is A Filtronic MMIC LNA. The LNA gain is around 11 ± 1 dB with 4 ± 0.5 dB noise figure and 13 ± 1 dBm saturated output power. The LNA dimensions are 1.45 × 1.1 × 0.1 mm. A wide band PHEMT MMIC SPDT is used,

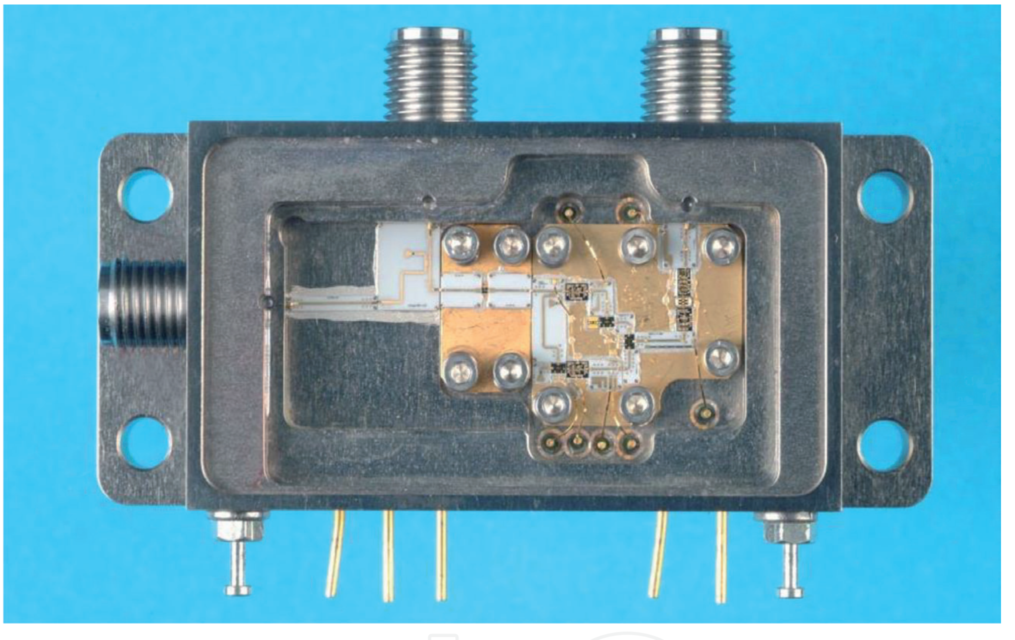

Figure 12.
18 to 40GHz frontend module.

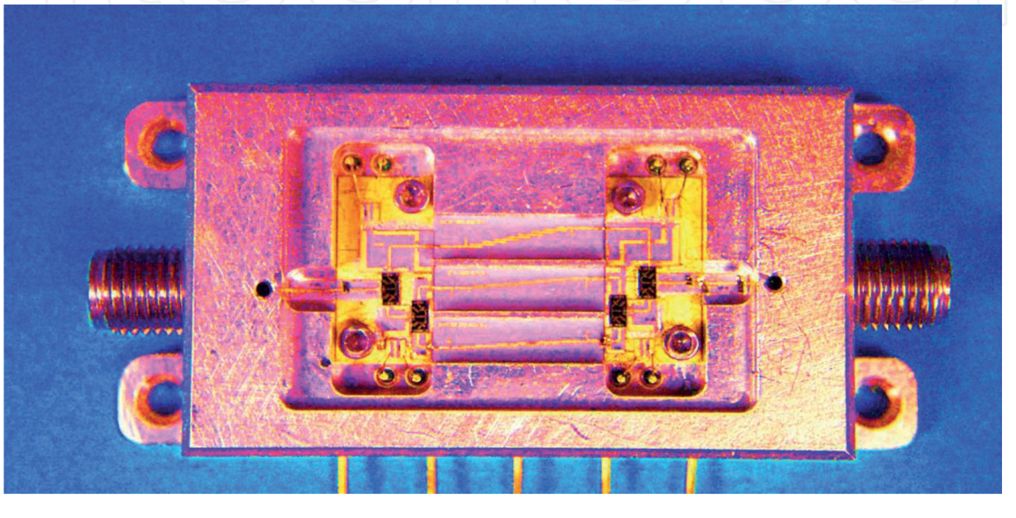

Figure 13.
A photo of UWB switched filter Bank.

AMMC-2008. The SPDT losses are lower than 2 dB. The isolation between the SPDT input port to the output ports is lower than -25 dB. The SPDT dimensions are 1 × 0.7 × 0.1 mm. The frontend electrical characteristics was evaluated by using ADS software.

Figure 13 presents a photo of the compact Switched Filter Bank SFB unit. The SFB Module consists of three side coupled microstrip filters. Each filter consists of nine sections. The filters are printed on a 5mil alumina substrate. A one to two dB attenuators connect the filters input and output ports to wide band MMIC switches. The attenuators are used to adjust each channel losses to the average required level. The module losses are adjusted to be higher in the low frequencies and lower in the high frequencies. AWR and ADS software were used to optimize the filter dimensions and structure. The SFB losses at high frequencies are around 9 dB and at the low frequencies the losses are around 10.5 dB.

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