Fabrication of MEMS Pressure Sensor on thin film membrane

Suchitav Khadanga
Millimeter Wave Devices Laboratory
Central Electronics Engineering Research Institute
Pilani - 333031, India

INTRODUCTION

A generalized Micro Electro Mechanical System (MEMS) consists of mechanical components, sensors, actuators and integrated circuit all integrated in the same environment. The evolution of MEMS has depended largely on the advancement in microfabrication technology for the development of solid state sensors and actuators.

Micro electromechanical Systems (MEMS) offer a powerful new technology for both optical and RF systems. The integration of optics and MEMS has created a new class of micro-opto-electro-mechanical devices and integrated circuits that are smaller, faster, more accurate, more rugged, and consume less power than macro scale devices. MEMS allows moveable micro-mechanical parts to be integrated with micro-optical elements and 3-D structures, enabling miniaturized free-space optical systems to be mass-produced at low cost by batch fabrication processes. Since the physical effect caused by mechanical movement is usually larger than conventional electro-optic or free-carrier effects, very efficient light modulators, switches, broadly tunable semiconductor lasers, detectors, and filters can be realized with the optical MEMS technology. Applications of optical MEMS include fiber optic switches, optical crossconnect, projection and headmount display, optical data storage, printing, optical scanners, modulators, fiber optic sensors, and packaging of optoelectronic components.

In the area of microwave/wireless communication, switches are widely used in RF/microwave systems and subsystems for signal routing, impedance matching, and amplifier gain adjustment. Traditional mechanical switches provide excellent electrical isolation and low contact resistance, yet they are heavy, bulky, and power hungry for switching control. Conventional solid state switches are small in size but have significant insertion loss (typically > 1 dB) and poor RF isolation (typically < -30 dB). So the design, fabrication, and performance of a MEMS switch that can handle broadband microwave signals while maintaining a minimal insertion loss and excellent electrical isolation. This MEMS switch uses a suspended silicon dioxide micro-beam as the cantilever arm, a platinum-to-gold electrical contact, and electrostatic actuation as the switching mechanism. Compared to its semiconductor counterparts, the MEMS switch is superior in both performance and power consumption.

Some of the other MEMS application include pressure sensors, accelerometers, micro valves, electromechanical switches and relays, inkjet nozzles, gyroscopes, micro manipulators and connectors, micro motors , AFM(Atomic Force Microscopy) tips and optical components like lenses, gratings, mirrors and tunable waveguides. The fabrication of these micro mechanical parts involves precise isotropic and anisotropic silicon etching, high aspect ratio lithography, silicon bonding techniques (Fusion bonding and Anodic bonding), plating, thin film deposition and standard I.C fabrication steps. Here one such MEMS component Pressure sensor is described. This includes MEMS overview, application area and fabrication process of MEMS pressure sensor. This work has done in Millimeter Wave Devices Laboratory of Central Electronics Engineering Research Institute, Pilani.

MEMS = Miniature Mechanical System + Integrated Circuit

MEMS Pressure Sensor

Micro fabricated pressure sensors comprise a small but useful subset of integrated circuits. Integrated sensors of high quality can be very sensitive to pressure changes, making them ideal for applications in which bulky machined sensors are not able to perform, or are too large, or consume too much power.

Typical applications of integrated pressure sensors include microphones, biomedical instrumentation (*e.g.*, blood and fluid pressure), vacuum sensing, wind-tunnel model instrumentation, automobile power and acceleration measurement, and even household electronics.

All mechanical sensors are based on material changes caused by stress placed on a membrane or other flexible element. On the submillimeter scale of integrated devices, materials like silicon show very little or no fatigue, which is apparently a macro scale phenomenon. Thus integrated sensors can be flexed indefinitely, and have a long lifetime. There also exist high-precision sensors based on capacitive effect. A membrane is also used, with one plate of a capacitor mounted on the membrane and the other plate suspended above it, usually fabricated on a relatively inflexible material such as Pyrex glass. The deflection of the membrane changes the distance between the plates and thus changes the capacitance. The other form of sensing pressure is through variation of resistance of resistors. Resistance is dependent on length and area. So when pressure is applied on the membrane the dimension of the membrane changes, in accordance the resistance changes. The change of resistance will change output voltage/current in the output. By proper calibration of the output voltage the pressure is detected. Here we will discuss regarding the pressure sensor based on resistors.

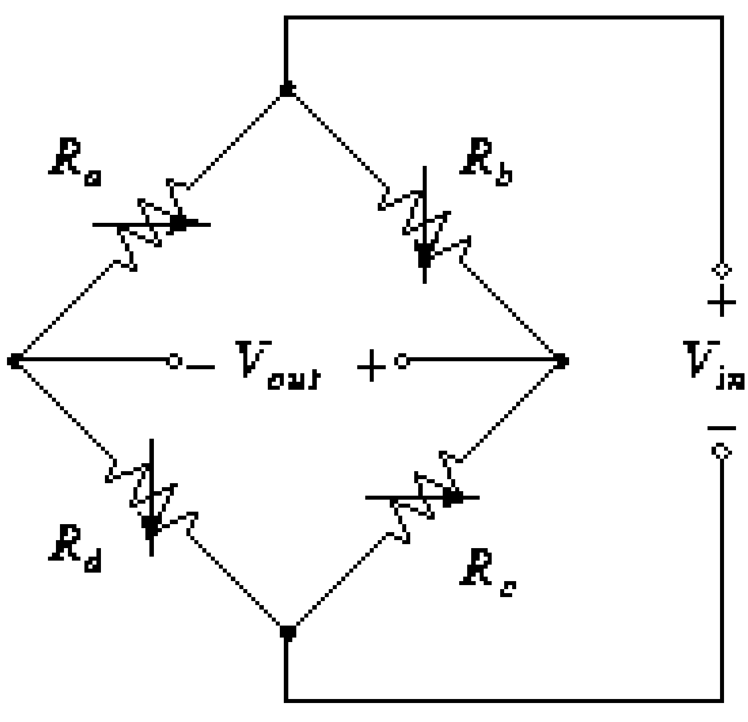
When standard or modified CMOS or bipolar processes are used in order to fabricate the sensor, signal processing can be done at the source. On-chip amplification of the signal is the first necessary step to ensure minimizing the effect of noise on the output. On-chip circuitry is also necessary in a high-quality system to compensate for temperature variation. Temperature-dependent behavior is seen as the limiting factor in integrated sensors.

Certain materials, of which Silicon is a notable example, are sensitive to changes resulting from stress applied to the crystal lattice. Resistance, in particular, is dependent on the changes in length caused by stress. Resistive changes are not isotropic, and can be divided into two independent functions, one component parallel to the direction of stress, and one component perpendicular to it, in the form of:

$$\left(\frac{\Delta R}{R}\right)_{II} = \pi_{II}\sigma_{II} + \pi_{\perp}\sigma_{\perp}$$

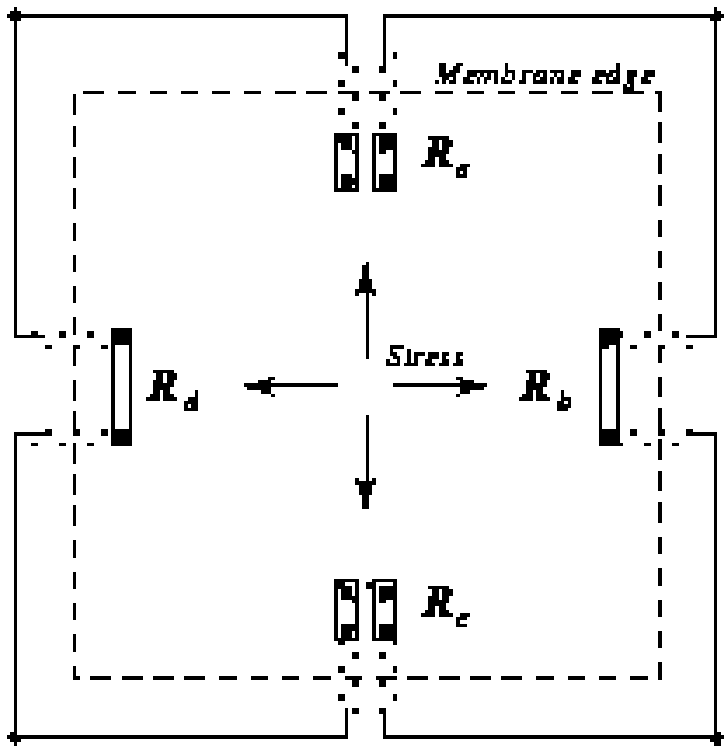
$$\left(\frac{\Delta R}{R}\right)_{\perp} = \pi_{II}\sigma_{\perp} + \pi_{\perp}\sigma_{II}$$

where $\sigma_{\perp}$ and σ_{II} are the perpendicular and parallel components of stress, respectively, and $\pi_{\perp}$ and π_{II} are the perpendicular and parallel resistive coefficients. The coefficients are functions of temperature and doping concentration. The stresses are proportional to pressure and to the square of the ratio L/h where *h* is the thickness of the membrane and L is the distance from the membrane center to the edge.
About the simplest sensor circuit that can be built using resistors is the Whetstone bridge, shown below.



Wheatstone Bridge circuit

The bridge is made of four resistors located on the four edges of the sensor membrane, close to the edges where the stress is greatest when vertical pressure is applied to the center (or uniformly across) the membrane. Two of the resistors are positioned parallel to the direction of the stress, and their resistance increases with pressure. The other two resistors are oriented perpendicular to the direction of the stress, and their resistance decreases with pressure. This configuration is shown in the figure below.



Configuration of resistors around a membrane.

The solution to the Wheatstone bridge as shown in the schematic above is:

$$V_{OUT} = V_{in}\left(\frac{R_c}{R_b + R_c} - \frac{R_d}{R_a + R_d}\right)$$

Resistors R_a and R_c are oriented parallel to the stress, and resistors and R_b are R_d oriented perpendicular to it. Thus when there is some variation of resistance due to applied pressure , the output voltage changes. This is the configuration of the fabricated sensor, with the resistor ends leading to bonding pads.

The pressure sensor can be integrated with integrated circuit to form the system.

FABRICATION STEPS

The Pressure sensor is fabricated using double side polished Silicon substrate. The fabrication steps are given below.

1. N-TYPE SILICON, Double side Polished
2. OXIDATION 0.8μM
3. Photolithography (Define Area)
4. Oxide etch for Active Area
5. Photolithography (Resistor Defining)
6. Boron Doping
7. Metallisation
8. Photolithography for metal contact
9. Initial Testing of Resistors
10. Back side photolithography
11. Bulk etching Silicon from Back side
12. Silicon to Glass Anodic Bonding for Mechanical Support
13. Final Testing

WHY Silicon

- As Hard as Diamond
- Elastic Limit More compared to Steel

Beyond Elastic Limit deformation of shape occurs in Steel but Silicon Breaks

- Saturated Technology
- MEMS Device can be integrated with other circuit components to form systems
- Silicon Surface when treated properly can provide optical surface of high quality. (Flat & Scatter free)
- Excellent mechanical properties of silicon allow fabrication of fatigue free devices.

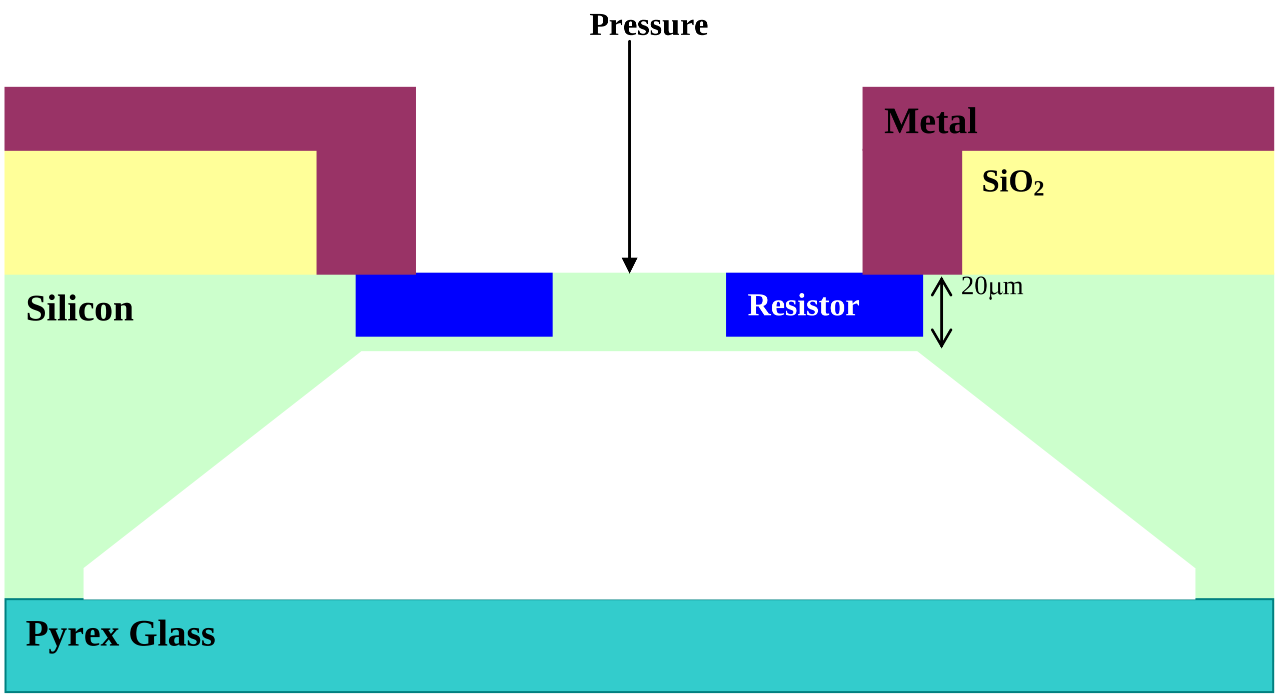
Photolithography

The Process of transferring patterns of geometric shapes on a mask to a thin layer of radiation sensitive material covering the surface of semiconductor wafer.

Steps

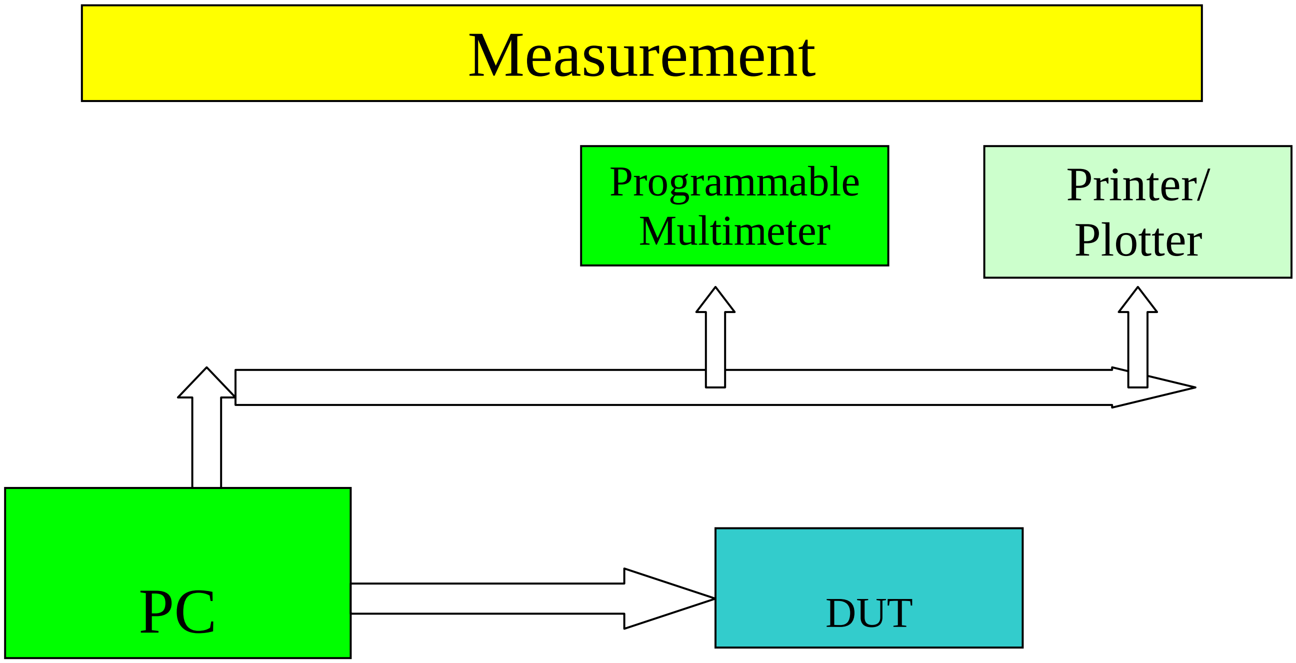
1. Apply Photo resist +ve
2. Spinned at 3000rpm for 20 sec
3. Prebake at 90^0C for 30 min
4. Allignment of specified mask
5. Exposure of UV ray for 14 sec
6. Developing 45 sec in +ve developer (1:1) DI
7. Post Baking at 140^0C for 30 min

Pressure sensor cross sectional view



Design of MEMS

1. Modeling (FEM, FDTD)
2. Design (Cadence, Tanner, Sonnet)
3. Simulation(Cadence, Tanner, Sonnet)
4. Layout (Cadence, Tanner)
5. Mask Preparation
6. Fabrication (Given in Fabrication Steps)
7. Testing



Shapes Can Be Fabricated using this technology

➢ Diapragms	: Pressure Sensor, Pumps
➢ Needles	: Connectors, MicroProbes, Heat Sinks
➢ Walls	: Heat Sinks
➢ Cantilevers	: Springs, Suspensions, Resonators
➢ Trenches & Grooves	: Gas Sensor, MicroChannel
➢ Pyramids	: Tips, Tactile Sensors
➢ Cavities & Holes	: Valves & Nozzles

Application Area

- Optical Communication
  - Precision micro components for micro optics
  - V-Grooves for optical Fiber
  - Digital Micro Mirror Devices
  - Optical Switches
  - WDM Components
  - Optical Attenuators
  - Tunable Lasers
  - Micro mirrors & micro lenses for wavelength selection and optical routing in network switches.

- RF MEMS

  - RF Switch
  - High Q inductors and capacitors
  - Tunable Wave guides

- Robotics
  - Tactile GRIP Sensors
  - Movement in 2-D/3-D Direction
  - Pattern and Speech Recognition
  - Guided Movement

- Computer Peripherals
  - Printer Heads, Disk heads
  - Laser Disk Heads
  - Micro Switches
  - Scanners and CD Writers
- Medical Prosthesis
  - Reciprocating, Rotary Movements
  - Crushing of Blood Clots
  - Slow Dispensing of Medicine
  - Smart on chip Clinical Analysis

-

Typical MEMS

- Micro Sensors
  - Pressure
  - Force
  - Acceleration
  - Vibration
  - Flow Rate etc.
- Micro Mechanical Actuators
  - Micro Relays
  - Micro Optical Components
  - Micro gas/ fluid dispensors
  - Micro flow controllers

FUTURE

- Micro Robots : To see, diagnose and correct a defect in an organ (Use Scalpel/Crushers/Dispenser)
- Optical Communication: WDM and DWDM Components
- High Quality Factor MMIC Components, inductor, capacitor,switch

Conclusion:

This pressure sensor is fabricated in Millimeter Wave Devices Laboratory of Central Electronics Engineering Research institute of Pilani. This is a part of work sponsored by ISRO, Bangalore. This work has done under guidance of Dr.S.Ahmad, Director, CEERI, Pilani and Dr. V.K.Dwivedi, senior scientist of CEERI, Pilani.

Thanks to all technical staff of microelectronics processing of CEERI, Pilani for their support during the fabrication process.

[31]Akbarzhon Madaminov, “Recommendation Systems”, Engpaper Journal
[32]Aathi oli.S , “REVIEW PAPER ON PHISHING ATTACKS”, Engpaper Journal
[33]Rania Fernando, “IoT based – Street Light Controlling System”, Engpaper Journal
[34]K. SAI BHARGAV, V. RAJENDRA, “Study on Data Structures for Machine Learning”, Engpaper Journal
[35]Brundha P, Guruprasad K N, Amith V Hiremath,Sirisha R, Chandrakanth G Pujari , “Face Detection Based Smart Attendance System Using Haar Cascade Algorithm”, Engpaper Journal
[36]Afsana Nadaf , “RFID BASED LIBRARY MANAGEMENT SYSTEM”, Engpaper Journal
[37]Mr. Vedant Thube, Neha Thakur, Mr. Siddhesh Balsaraf,Ms. Priyanka Hanchate, Dr. S. D. Sawarkar , “Accident Prevention using Eye Drowsiness & Yawning Detection”, Engpaper Journal
[38]Abhishek A Hishobkar, Rutuja Gaonkar, Jagdish Chintamani , “DIGITAL DIARY”, Engpaper Journal
[39]Pooman Suryavanshi, Aryan Ghadge, Manali Kharat , “TAXI SERVICE for VISUALLY IMPAIRED”, Engpaper Journal
[40]Mr. Pankaj yadav, Shila Jawale, Mr. Ashutosh Mahadik, Ms. Neha Nivalkar, Dr. S. D. Sawarkar , “NEWS ARTICLES CLASSIFICATION”, Engpaper Journal
[41]Rahul Chavan, Manvee Bhoir, Gaurav Sapkale, Anita Mhatre, “Smart Tourist Guide System”, Engpaper Journal
[42]Rutik Desai, Akash Jadhav,Suraj Sawant ,Neha Thakur , “Accident Detection Using ML and AI Techniques”, Engpaper Journal
[43]Anagha Vishe,Akash Shirsath, Sayali Gujar, Neha Thakur , “Student Attendance System using Face Recognition”, Engpaper Journal
[44]Ms.Sayali Patekar, Shila jawale, Ms.Pranali Kurhade, Mr.Shubham Khamkar , “Smart Classroom Application”, Engpaper Journal
[45]DOSHI SAKSHI, DEVYANI CHAUDHARI, POOJA GAIKWAD, RUTUJA CHABUKSWAR,MRS. SUJATA KOLHE, “TOURISM SIMPLIFIED THROUGH VOICE”, Engpaper Journal
[46]Afreen Fathima,Samreen Jameel, Pathan Ahmed khan , “ACCIDENT DETECTION AND ALERTING SYSTEM”, Engpaper Journal
[47]Suman Zareen, Tuba Masood, Pathan Ahmed khan, “E-Commerce Web Application with Augmented Reality”, Engpaper Journal
[48]Lok Shan CHAN, “Selection of Waterfall and Agile Methodologies in Software Testing”, Engpaper Journal
[49]Barve Rutu, “CLOUD COMPUTING SYSTEM FOR GAMING”, Engpaper Journal
[50]Harshvardhan Singh, “Machine Learning: Fake News Blocking”, Engpaper Journal
[51]M.Al Batahari, “SERVERS ROOM MONITORING SYSTEM USING IOT”, Engpaper Journal
[52]AYUSHI ANKITA RAKSHIT, “VIRTUAL MASTER USING PYTHON”, Engpaper Journal
[53]Baldeep Kaur, “REAL TIME SLEEP DROWSINESS DETECTION USING FACE RECOGNITION”, Engpaper Journal

[54]Suchitav Khadanga, "Two Stage CMOS Operational Amplifier From Specification to Design", Engpaper Journal
[55]nidhi sharma, "Introduction to Remote Sensing", Engpaper Journal
[56]Rohith N Reddy, "COVID-19 Detection using SVM Classifier", Engpaper Journal
[57]Swapnil Kole, "COVID-19 Database on Consortium Blockchain", Engpaper Journal
[58]TejalLengare, PallaviSonawane, PrachiGunjal, ShubhamDhire, Prof.Shaikh.J.N , "Accident Detection & Avoidance System in Vehicles", Engpaper Journal
[59]Abhishek Pawshekar, Deepti More, Akash Khade, Pratiksha Wagh, Ganesh Ubale, "Augmented Reality: to converting and placing object into 3D model", Engpaper Journal
[61]Prof.Ubale.G.S, Pranjal Adhav,Pooja Gaikwad, Sushama Nadavade ,Pooja Kale , "Iot based Bridge Monitoring System", Engpaper Journal
[62]Divya Deewan, Priyanka Maheshwari, Sanjay Jain, "A REVIEW OF BATTERY-SUPERCAPACITOR HYBRID ENERGY STORAGE SYSTEM SCHEMES FOR POWER SYSTEM APPLICATION", Engpaper Journal
[63]Prof.Ansari.M.B, Pranjal Adhav,Pooja Gaikwad,Sushama Nadavade,Pooja Kale, "Survey on MyHelper IOT based Bridge Monitoring System", Engpaper Journal
[64]Shreyas.S.J, Saddam hussain, Chaithra E, "COMPARATIVE STUDY ON SEISMIC RESPONSE OF MASONRY INFILLED RC FRAME BUILDINGS AND MIVAN BUILDINGS WITH DIFFERENT PERCENTAGE OF WALL OPENINGS", Engpaper Journal
[65]Yusuf Ali Hassan, "Somali Power-Grid Significant Challenges", Engpaper Journal
[66]Ahmed N. Elhefnawy, "Refractive IR Objective Optical Design Operating in LWIR band For Military Observation Applications", Engpaper Journal
[67]S MANJULA, D SELVATHI and SUCHITAV KHADANGA, "Design of low-power CMOS transceiver front end for 2.4-GHz WPAN applications", Engpaper Journal
[68]Suchitav Khadanga, "Fabrication of MEMS Pressure Sensor on thin film membrane", Engpaper Journal
[69]Suchitav Khadanga and Dr. K.R.Suresh Nair, "An Introduction to Bluetooth", Engpaper Journal
[70]Suchitav Khadanga and S. Ahmad, "DESIGN AND FABRICATION OF LOW COST MICROWAVE OSCILLATOR", Engpaper Journal
[71]Ameen Ahmed, Noushad S, Suchitav Khadanga, K.R.Suresh Nair, P.K.Radhakrishnan, "DEVELOPMENT OF LOW PHASE NOISE SMALL FOOT PRINT SURFACE MOUNT VOLTAGE CONTROLLED OSCILLATOR", Engpaper Journal
[72]Suchitav Khadanga , "Synchronous programmable divider design for PLL Using 0.18 um cmos technology", Engpaper Journal
[73]Kavya.G.R, Shivaraju.G.D, Dr. T V Mallesh, S R Ramesh, "PROGRESSIVE COLLAPSE RESISTANCE OF FLAT SLAB BUILDING", Engpaper Journal