RF MEMS AND SOLID STATE SWITCHES

Anand Bharti
18EC01029

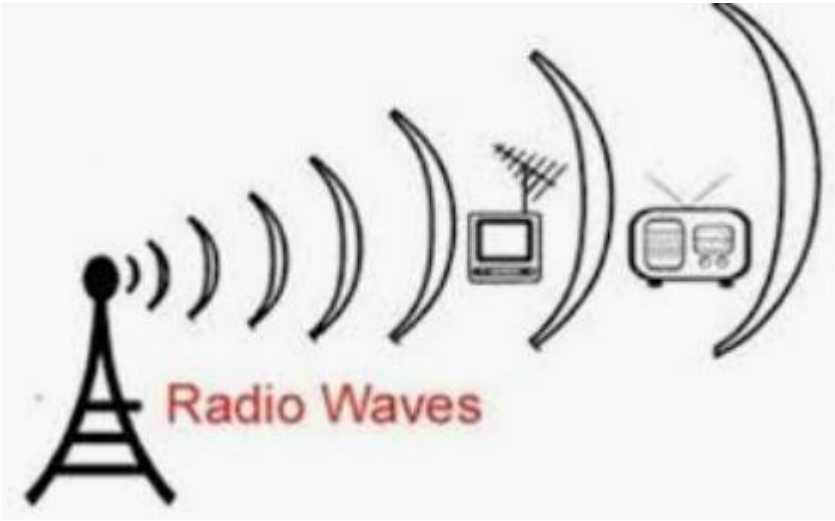
Outline:

- Introduction
- Parameter
- MEMS Switches
  - Introduction
  - Working
  - Advantage and Disadvantage
- Solid State Switches
  - Introduction
  - PN junction diode as switch
  - PIN diode as switch
  - SPST, SPDT switch using PIN diode
  - Advantage and Disadvantage
- Application

Introduction

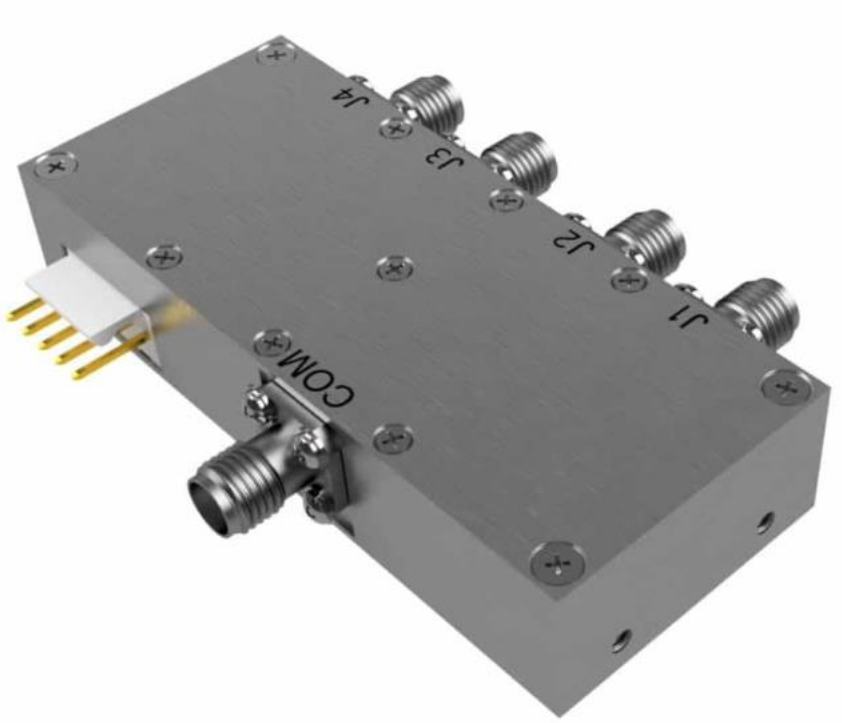
- Radio waves are electromagnetic waves within the frequencies 300KHz - 300GHz, and include microwaves.
- There are many application of Radio waves

e.g. Vehicle monitoring, Remote control, Small range wireless network etc.



Parameter of RF switch

- 1: Insertion loss
- 2: Switching speed
- 3: Power handling
- 4: Operating life
- 5: Isolation



Parameter of RF switch

1: Insertion loss

Insertion loss of a switch module at particular frequency can be used to calculate the power loss caused by the switch on a signal at that frequency.

$$Insertion\ Loss\ (dB) = 10\log\left(\frac{P_{IN}}{P_{OUT}}\right) = -10\log\left(\frac{P_{OUT}}{P_{IN}}\right)$$

$$Insertion\ Loss\ (dB) = 20\log\left(\frac{V_{IN}}{V_{OUT}}\right) = -20\log\left(\frac{V_{OUT}}{V_{IN}}\right)$$

2: Switching speed

It is defined as the time needed to change the state of a switch port (arm) from "ON' to "OFF" or from "OFF" to "ON".

Parameter of RF switch

3: Power handling

Power handling defines the ability of a switch to handle power. It is very dependent on the design and materials used for switch.

- 4: Operating life

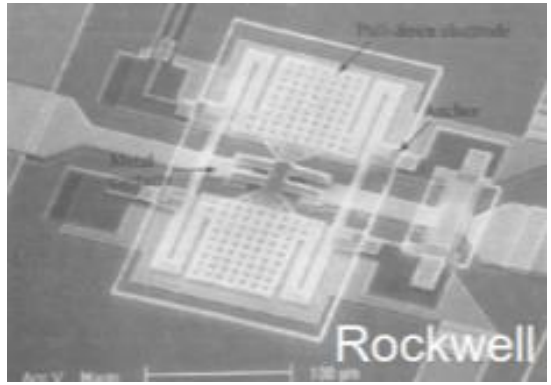
The operating life specifies the minimum number of switch cycles. A long operating life reduces cost per cycle.

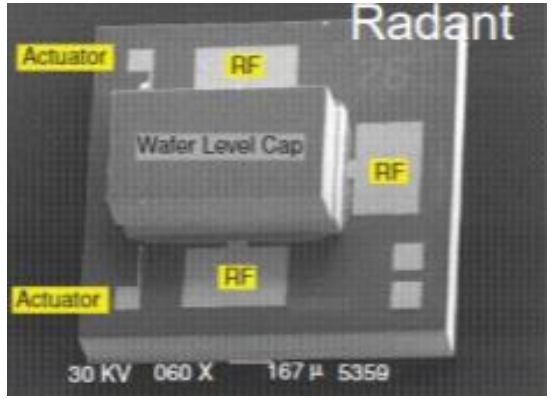
- 5:Isolation

Isolation is a measure of how effectively a Switch is turned OFF.

History of MEMS Switches

- 1990s: First publications (Hughes Research Lab, Rockwell Science, TI)
- 2001: more than 30 companies working on RF MEMS switches (including Motorola, Analog Devices, Samsung, ST-microelectronics, Thales) and various research labs worldwide .
- Excellent RF performance, but major reliability issues hindered industrialization .
- 2003: First products announced (Magfusion, Terravicta, Radant) but no success.
- A lot of companies stopped their activities .
- Since 2013: Several new products that seem to be successful (WiSpry, Cavendish Kinetics, Analog Devices)





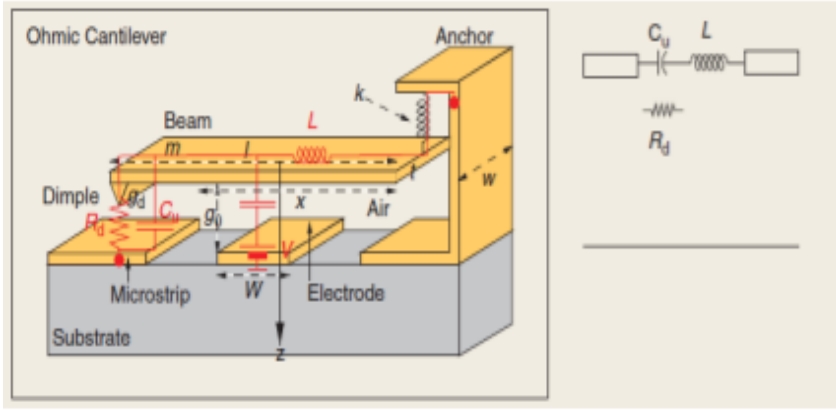
Introduction

- MEMS = Microelectromechanical system
- RF MEMS switches can be stand alone devices (e.g. SPST, SPDT or xPyT) or be used in RF Circuits (phase shifters, filters, ..)
- MEMS switches usages some mechanical movement to achieve a closed or open circuit

Types (principle of switching):

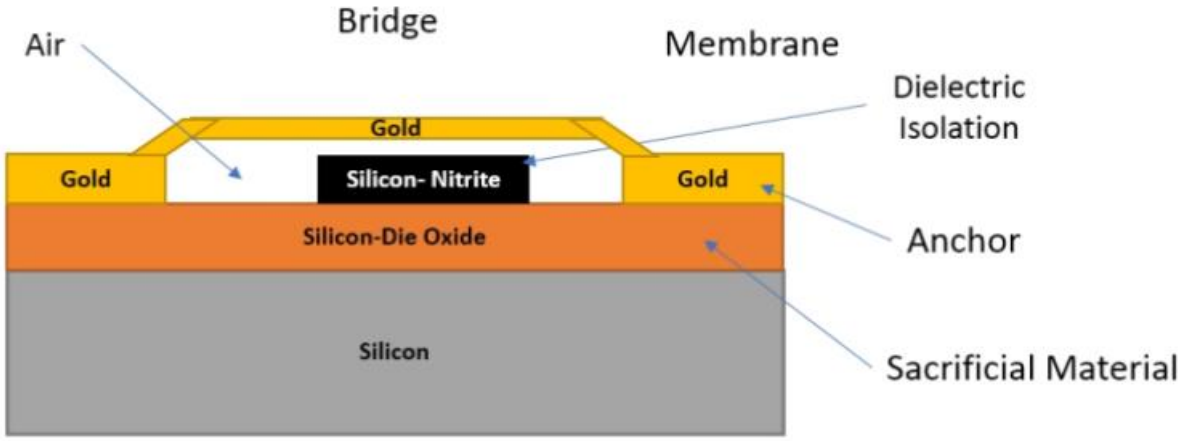
(1) Capacitive MEMS switch

(2) Resistive MEMS switch

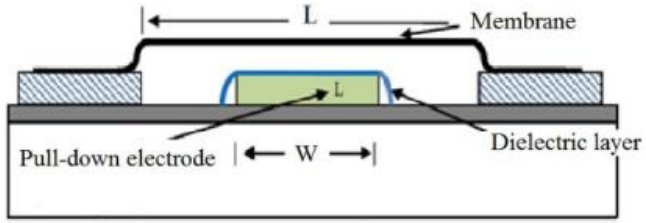


source: http://microwave-rf.com/documents/10h30%2011h00%20Presentation%20Antenna%20symposium%20for%20publication.pdf

Capacitive RF MEMS Switch



- The above design is electrostatically actuated capacitive fixed-to- fixed bridge base capacitive switch.
- Silicon nitride thin film dielectrics are used in capacitive radio frequency micro-electromechanical systems (MEMS) switches since they provide a low insertion loss, good isolation, and low return loss.
- A capacitor is built up between the fixed electrode and movable electrode.
- Electrostatic activation mechanism
- Operating frequencies from 10 to 100 GHz, losses 0.2 dB, isolation from 15 to 35 dB for operating frequencies

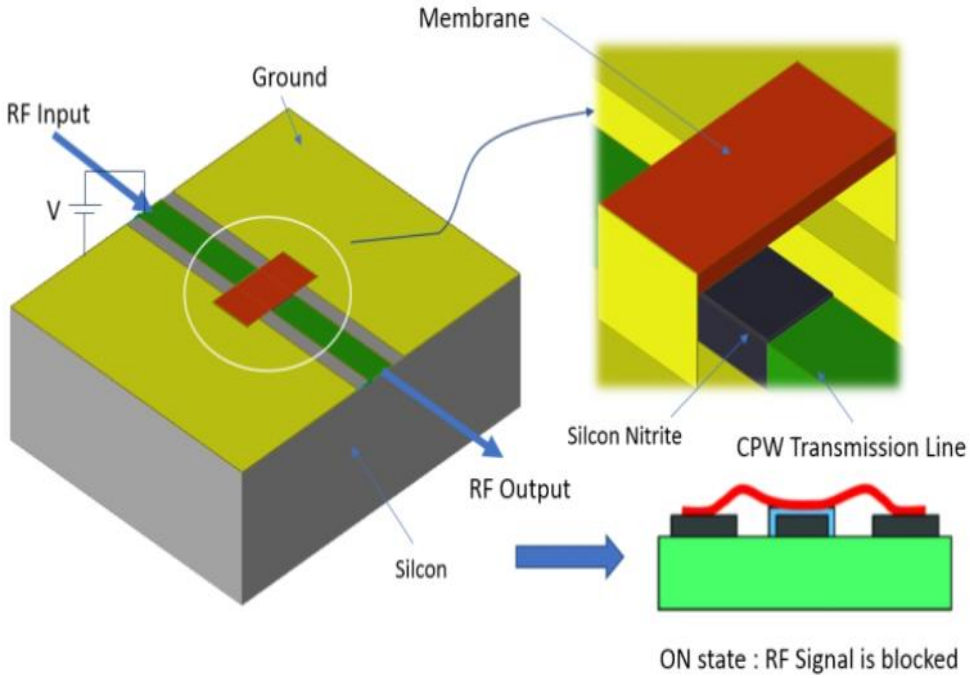


Source : https://www.analogictips.com/capacitive-rf-mems-switch-desig
Analytical Approach in the Development of RF MEMS Switches by Sherova and
Alexander V. Nikitin.

Working:

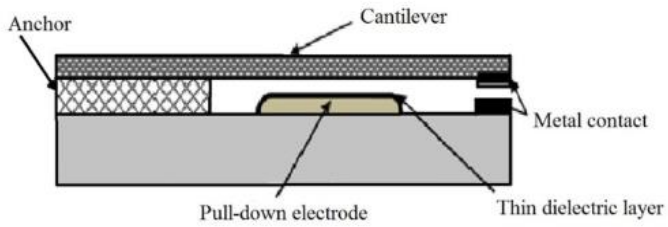
- beam is fixed at both the ends and voltage is applied in the middle of the beam to note down the displacement of the beam towards substrate.
- The actuation voltage or applied voltage or pull in voltage is the maximum voltage at which the electrostatic force becomes superior over mechanical restoring force, causes MEMS device pull down towards the ground plane

- When the cantilever will deform and touches to ground under this condition the output is zero. The switch closing time depends on the actuation voltage and the opening time depends on the mechanical properties of the switch.



Source:https://www.analogictips.com/capacitive-rf-mems-switch-design-and-simulation/

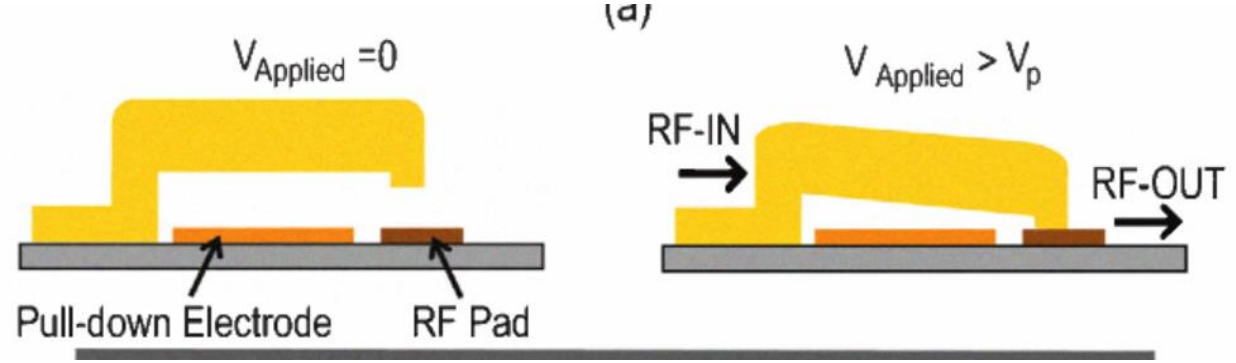
Resistive MEMS Switches



- The above design is electrostatically actuated capacitive fixed-to- fixed bridge base resistive switch
- Sufficiently high control voltage—from 60 to 80 V

Source : Analytical Approach in the Development of RF MEMS Switches by gor E. Lysenko, Alexey V. Tkachenko1,Elena V. Sherova and Alexander V. Nikitin.

Working:



- beam is fixed at one the ends and voltage is applied in the middle of the beam to note down the displacement of the beam towards RF pad.
- The actuation voltage or applied voltage or pull in voltage is the maximum voltage at which the electrostatic force becomes superior over mechanical restoring force, causes MEMS device pull down towards the RF Pad.
- When the cantilever will deform and touches to RF Pad under this condition the switch is on . The switch closing time depends on the actuation voltage and the opening time depends on the mechanical properties of the switch.

Source : Variable spring constant, high contact force RF MEMS switch

Advantage

- High isolation relative to other RF switches
- Power consumption close to zero
- Very low insertion loss

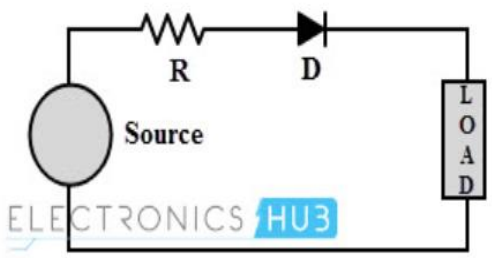
Disadvantage

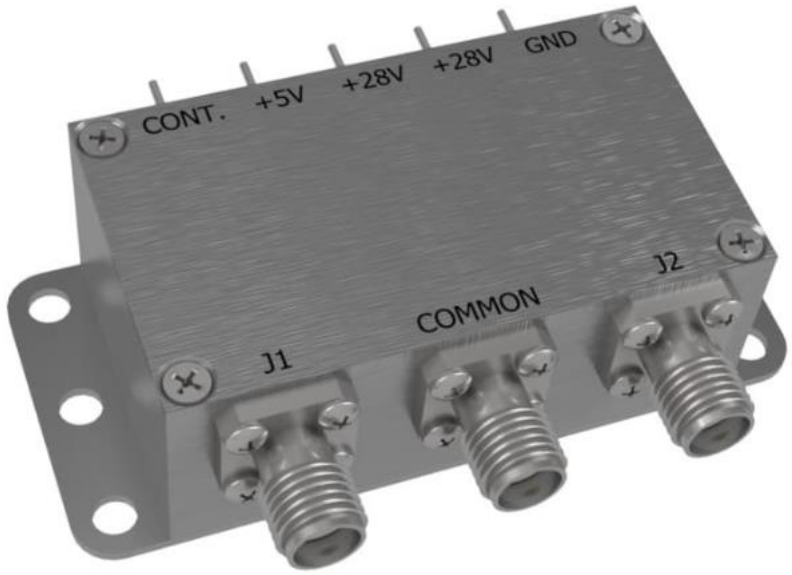
- More costly relative to solid state switches.
- high switching time
- require large values of control voltage (40–100 V for pull-down voltage and 15–30 V for hold-down voltage, respectively)

Solid State Switches

- **Solid state switches** do not require any physical contact in order to control a circuit. These are activated by semiconductor action.

  e.g. PN junction diode, PIN DIODE, MOSFETs etc.





PN junction Diode as switch

- It is two terminal device.

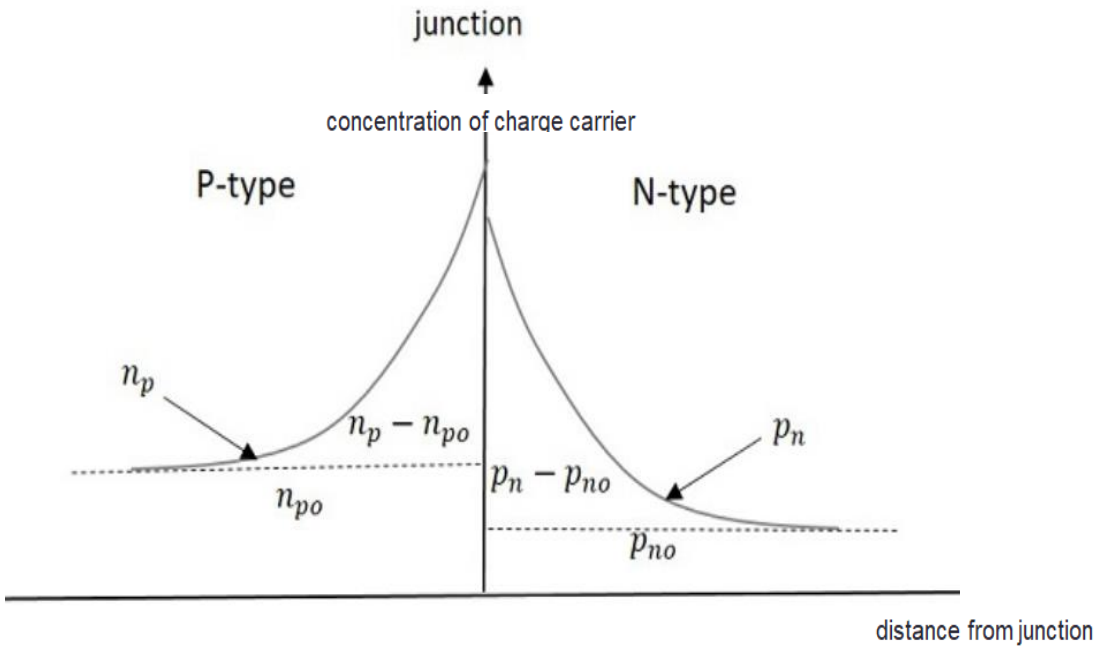
Diode Switching Times:

- The time taken before the diode recovers its steady state is called as Recovery Time.
- The time interval taken by the diode to switch from reverse biased state to forward biased state is called as Forward Recovery Time.
- The time interval taken by the diode to switch from forward biased state to reverse biased state is called as Reverse Recovery Time.

Continued

- **During Forward biased Condition**

  The minority carriers are more near junction and less far away from the junction.



graph source

https://www.tutorialspoint.com/electronic_circuits/electronic_circuits_diode_as_switch.htm

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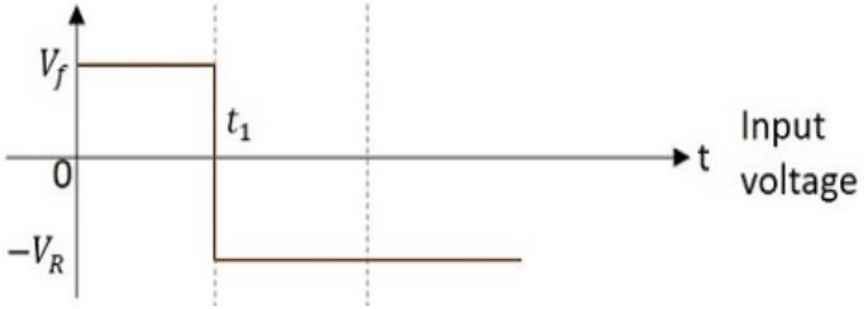
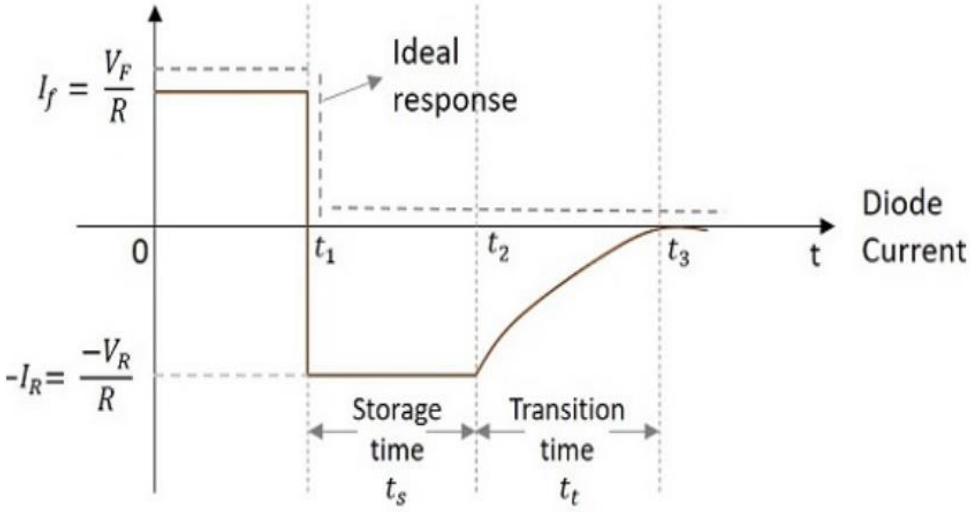

V_f
t_1
0
$-V_R$
t
Input
voltage


$I_f = \frac{V_F}{R}$
Ideal
response
0
t_1
t_2
t_3
t
Diode
Current
$-I_R = \frac{-V_R}{R}$
Storage
time
t_s
Transition
time
t_t

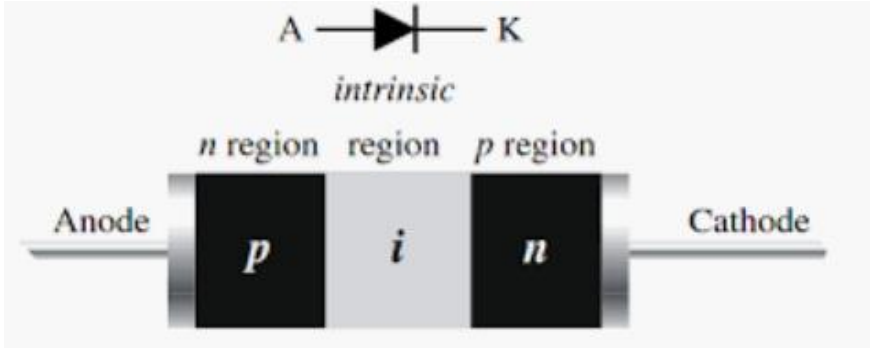
Limitation

- Due to diode high recovery time, it’s never goes in off state for microwave frequency.

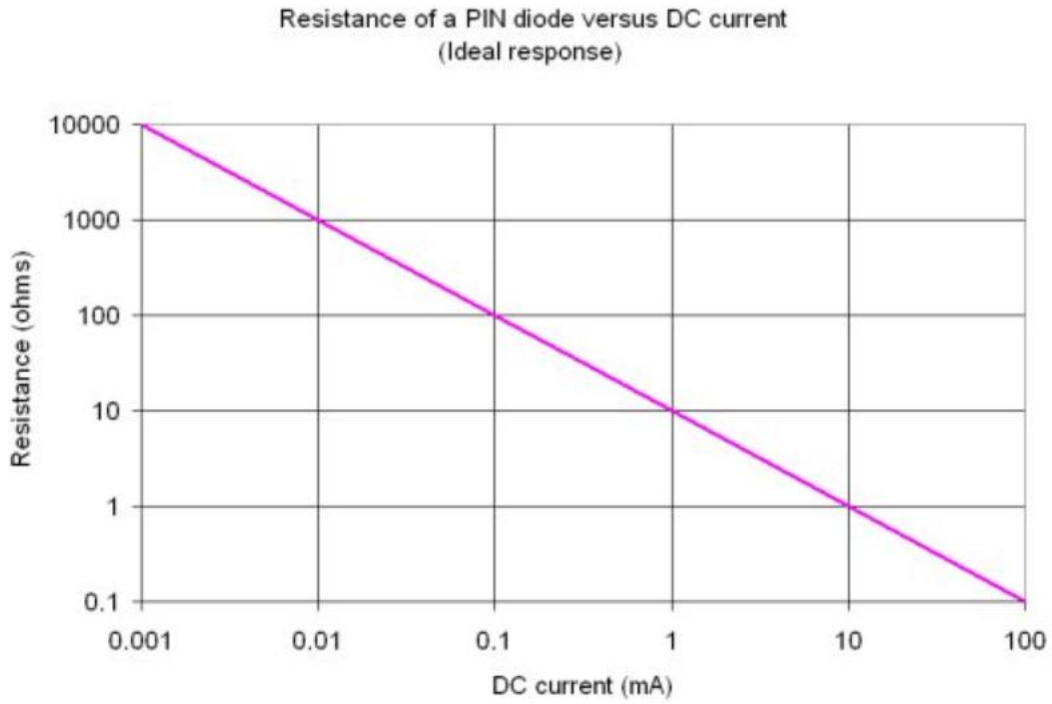
- Works better for low frequency or DC but doesn’t work good for high frequency.

PIN diode as RF switch

- A **PIN diode** is a diode with a wide, undoped intrinsic semiconductor region between a p-type semiconductor and an n-type semiconductor region.
- The p-type and n-type regions are typically heavily doped.



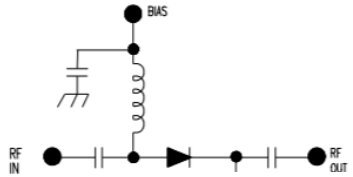
Characteristic of PIN Diode

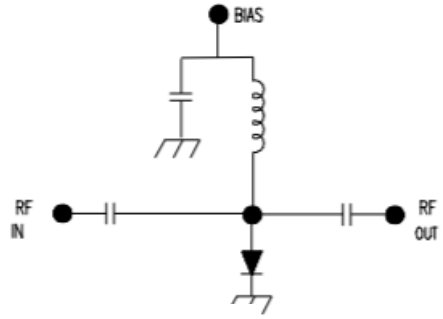


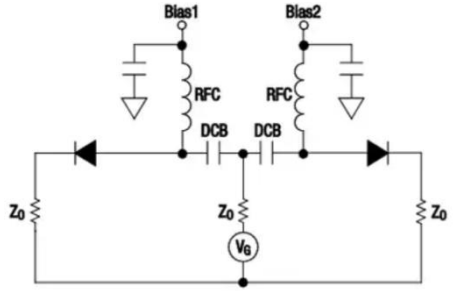
At RF frequency

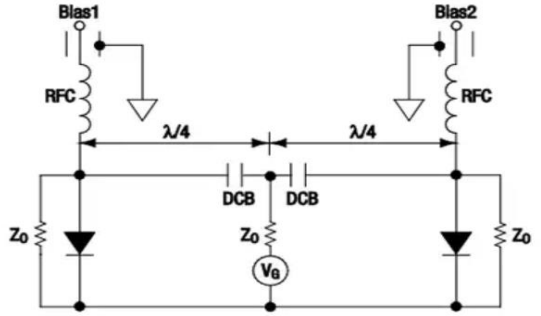
Source:https://www.microwaves101.com/encyclopedias/pin-diodes

- 1:SPST Switch
- (a) *PIN diodes used in series mode*
- (b) *PIN diodes used in shunt mode*
- 2:SPDT Switch
- (a) *PIN diodes used in series mode*
- (b) *PIN diodes used in shunt mode*









Advantage

- high speed operation
- Small size and weight, as well as low-power control
- Cheap relative to other switch
- Easy to manufacturing

Disadvantage

- Low isolation
- higher losses

key desirable parameters in RF switches

- low insertion loss and return loss (reflection) in closed state
- high isolation
- high power-handling capability during switching
- low operating voltage
- high reliability (particularly a large number of cycles before failure)
- small size
- and low cost

Comparison b/w PIN diode and MEMS switches

Parameter	RF MEMS	PIN
Voltage (V)	10-80	±3-5
Current (mA)	0	3-20
Power consumption (mW)	0.05-0.1	5-100
Switching time	1-300 μs	1-100 ns
C_{up} (series) fF	1-6	40-80
R_s (series) Ω	0.5-2	2-4
Capacitance ratio	40-500	10
Cutoff frequency (THz)	20-80	1-4
Isolation (1-10 GHz)	Very high	High
Isolation (10-40 GHz)	Very high	Medium
Isolation (60-100 GHz)	High	Medium
Loss (1-100 GHz) (dB)	0.05-0.2	0.3-1.2
Power handling (W)	<1	<10
Third-order intercept point (dBm)	+66-80	+27-45

Source: Modeling of RF MEMS switches and development of RF By Shimul Chandra Saha

Application

- satellites
- space based communication systems
- RF antenna
- Very small aperture terminal (VSAT)
- Bluetooth accessories
- remote keyless entry systems
- GPS navigation systems

Refrence

- https://www.tutorialspoint.com/electronic_circuits/electronic_circuits_diode_as_switch.htm
- https://en.wikipedia.org/wiki/PIN_diode.
- https://www.microwaves101.com/encyclopedias/pin-diodes.
- https://en.wikipedia.org/wiki/RF_switch.
- https://www.ieee.li/pdf/essay/pin_diode_handbook.pdf
- Modeling of RF MEMS switches and development of RF By Shimul Chandra Saha
- https://www.analogictips.com/capacitive-rf-mems-switch-design-and-simulation/
- Analytical Approach in the Development of RF MEMS Switches by gor E. Lysenko, Alexey V. Tkachenko1,Elena V. Sherova and Alexander V. Nikitin.

THANK YOU