MMIC Design and Technology
Passive Elements

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Lecture 3 Passive Elements

Types of Passive Elements

- Resistors
- Capacitors
- Transmission Lines
- Inductors
- Couplers

Resistor

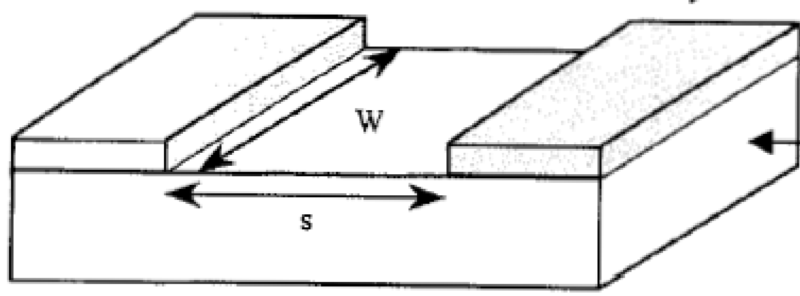


Figure 2.5 Schematic of a generic resistor

The resistance is given by:

$$R = R_{sh}\frac{s}{W} + 2R_c \qquad (2.1)$$

where R_{sh} is the sheet resistance of the metal film or doped semiconductor region

s is the separation between ohmic contacts (defining the length of the resistor parallel to current flow)

W is the width of the resistor in the direction perpendicular to current flow

R_c is the resistance of the contact at either end of the structure

Types of Resistors

- Thin Film
  - NiCr
  - 50 Ω/sq
- Bulk
  - GaAs
  - 700 Ω/sq

Figures from Text

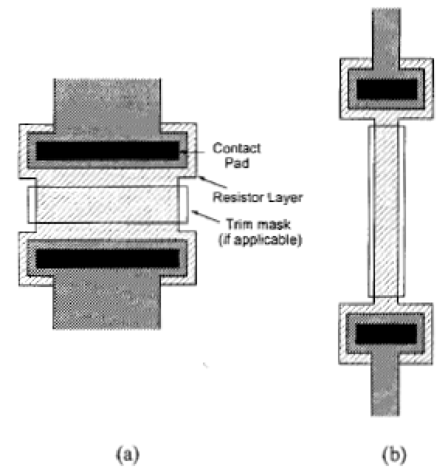


Figure 3.10 Resistor examples: (a) small value (≈ 50 Ω) and (b) large value (≈ 3000 Ω)

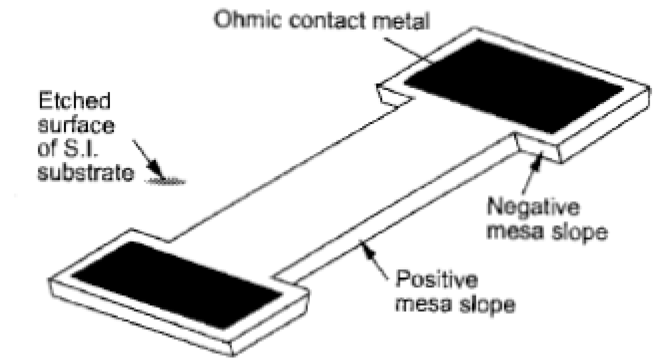


Figure 3.11 Mesa resistor view showing positive and negative mesa edges

Resistor Equivalent Circuit

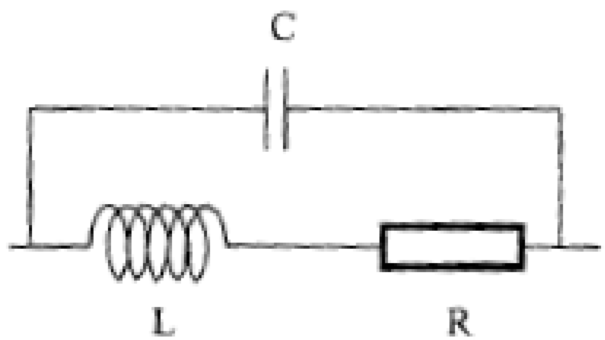


Figure 2.6 Lumped-element equivalent circuit of a resistor

Capacitor

$$C = \frac{A\varepsilon_0\varepsilon_r}{d}$$

$\varepsilon_r =$ 13 GaAs

$$\varepsilon_0 = 8.85x10^{-12}\frac{F}{m} = 8.85x10^{-15}\frac{F}{mm}$$

Typical chip has *d*= 0.1mm

What is C in pF/mm^2

MIM Capacitor

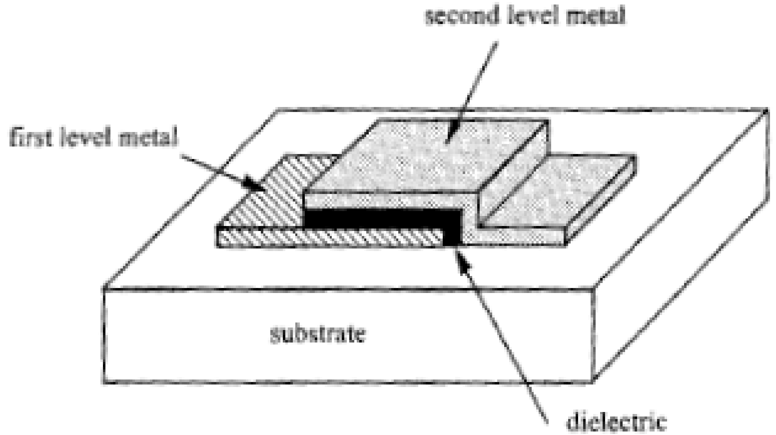
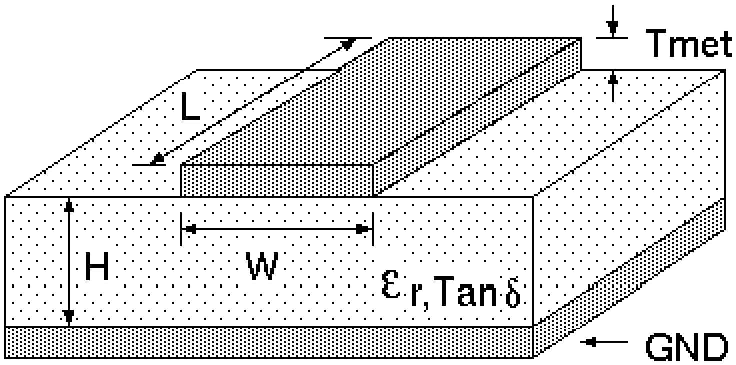


Figure 2.7 Schematic of a metal-insulator-metal capacitor

Thin Dielectric layer to produce high values of capacitance

1200pF/mm^2

Microstrip



http://mcalc.sourceforge.net/

$$\varepsilon = \varepsilon_{\mathrm{Re}} + j\varepsilon_{\mathrm{Im}}$$

$$\tan\delta = \frac{\varepsilon_{\mathrm{Re}}}{\varepsilon_{\mathrm{Im}}}$$

GaAs

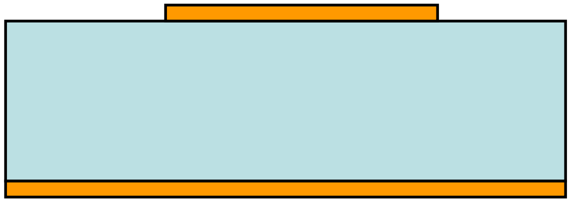
$$\varepsilon_r = 13$$

$$\tan\delta = 0.0016 \text{ @ } 10\text{GHz}$$

Effective Dielectric Constant

$$when \left(\frac{W}{H}\right) \geq 1$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12\left(\frac{H}{W}\right)}}$$



$$when \left(\frac{W}{H}\right) < 1$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1 + 12\left(\frac{H}{W}\right)}} + 0.4\left(1 - \left(\frac{W}{H}\right)\right)^2\right]$$

Impedance

$$when \left(\frac{W}{H}\right) \geq 1$$

$$Z_0 = \frac{120 \pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{H} + 1.393 + \frac{2}{3}\ln\left(\frac{W}{H} + 1.444\right)\right]}$$

$$when \left(\frac{W}{H}\right) < 1$$

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}}\ln\left(8\frac{H}{W} + 0.25\frac{W}{H}\right)$$

Wavelength λ

$$c_m = f\lambda$$

$$c_m = \frac{c_0}{\sqrt{\varepsilon_r}}$$

In GaAs

$$c_m = \frac{c_0}{\sqrt{13}} = 8.3x10^9 \frac{cm}{\sec}$$

At 10GHz *f* = 0.83 cm

Propagation Modes

- Microstrip supports TEM modes
  - $\lambda_g = c_m / f$
- Must be thin to avoid higher order modes
- Thin means H < 0.1 λ
  - <0.8mm at 10GHz
  - <0.25mm at 30GHz

Transmission Line Losses

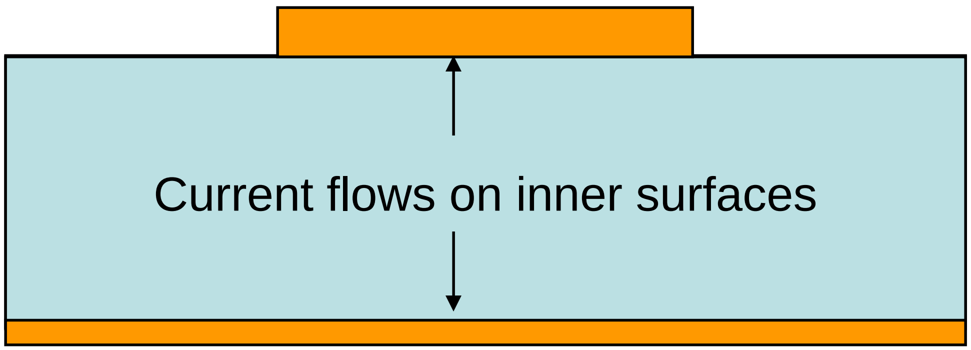
- Skin Depth

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

$\sigma =$ Conductivity gold = 4.5 x 10^7 S/m

$$\mu = 4\pi x 10^{-7} \frac{H}{m}$$

Current flow on microstrip



Simple Inductors

From Text

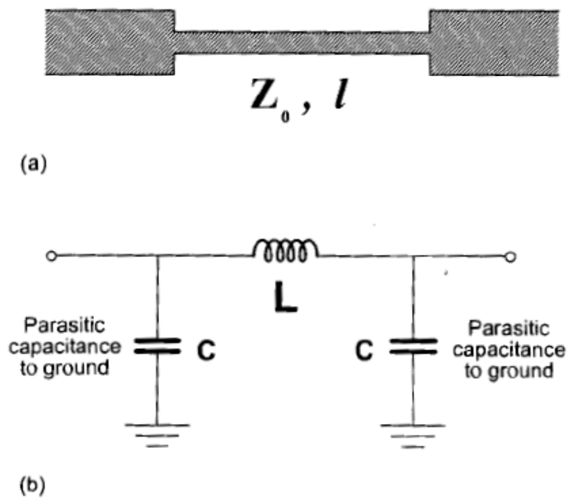


Figure 3.1 The ribbon inductor: (a) microstrip layout and (b) equivalent circuit

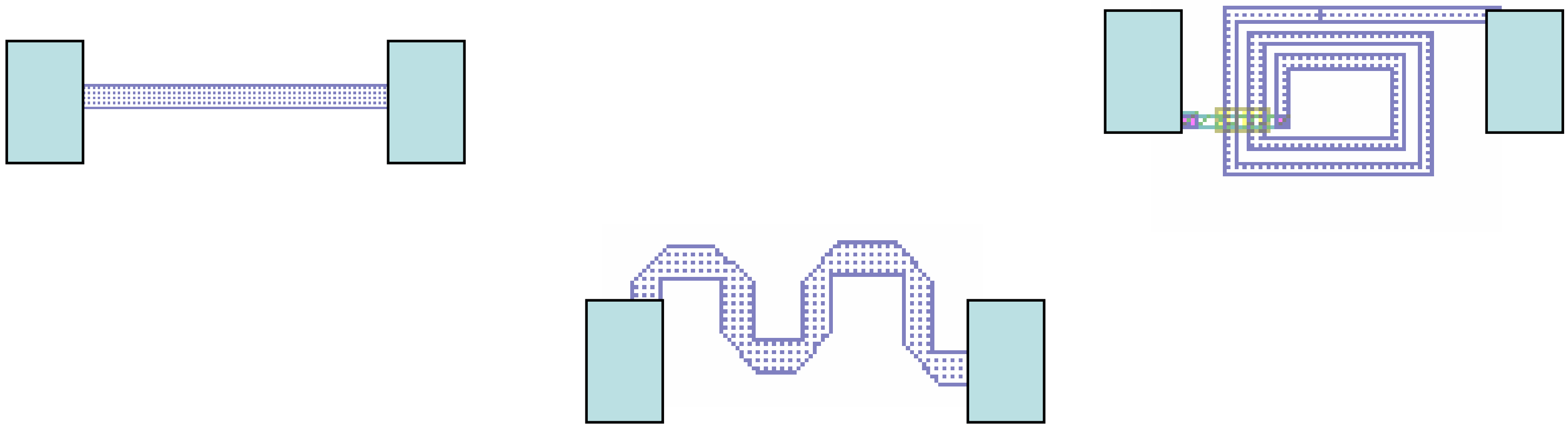
$$L = \frac{Z_0}{2\pi f}\sin\left(\frac{2\pi l}{\lambda_g}\right) \tag{3.1}$$

and

$$C = \frac{1}{2\pi f Z_0}\tan\left(\frac{\pi l}{\lambda_g}\right) \tag{3.2}$$

Inductor Designs

- May require Electromagnetic Solution
  – Some design equations available
  – Use foundry supplied models



Vias and Grounding

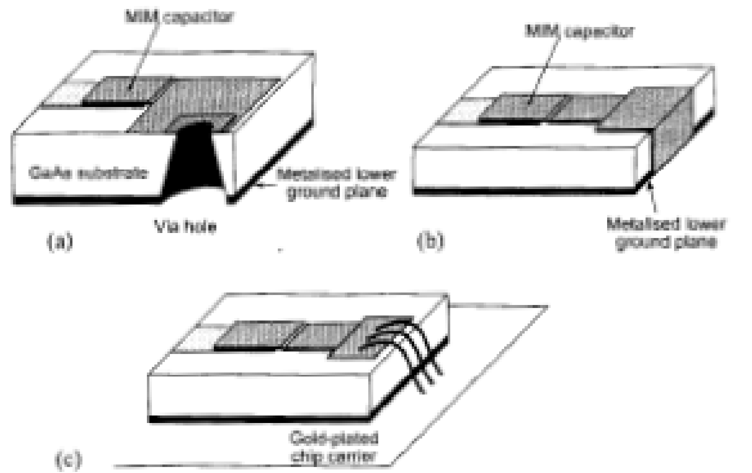


Figure 3.13 Grounding methods: (a) through-substrate via-holes, (b) wrap-around grounding and (c) bond-wires

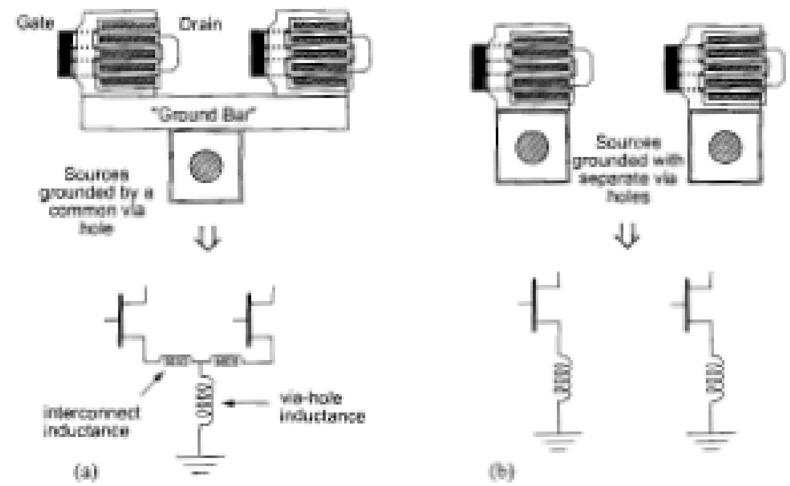


Figure 3.14 An example of improper grounding: (a) FETs with a common source ground pad, leading to unwanted feedback and (b) solution: separate source ground pads

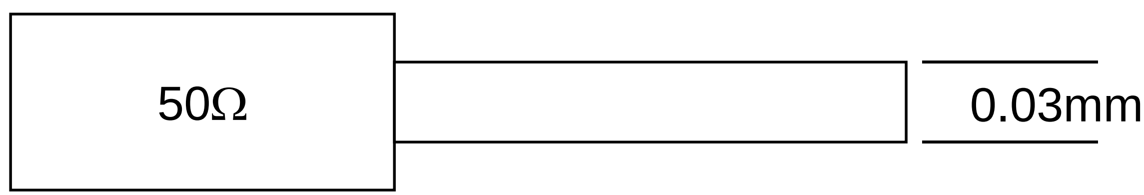
Impedance Example

Consider 0.1 mm thick GaAs
Find W for 50Ω line

0.07mm

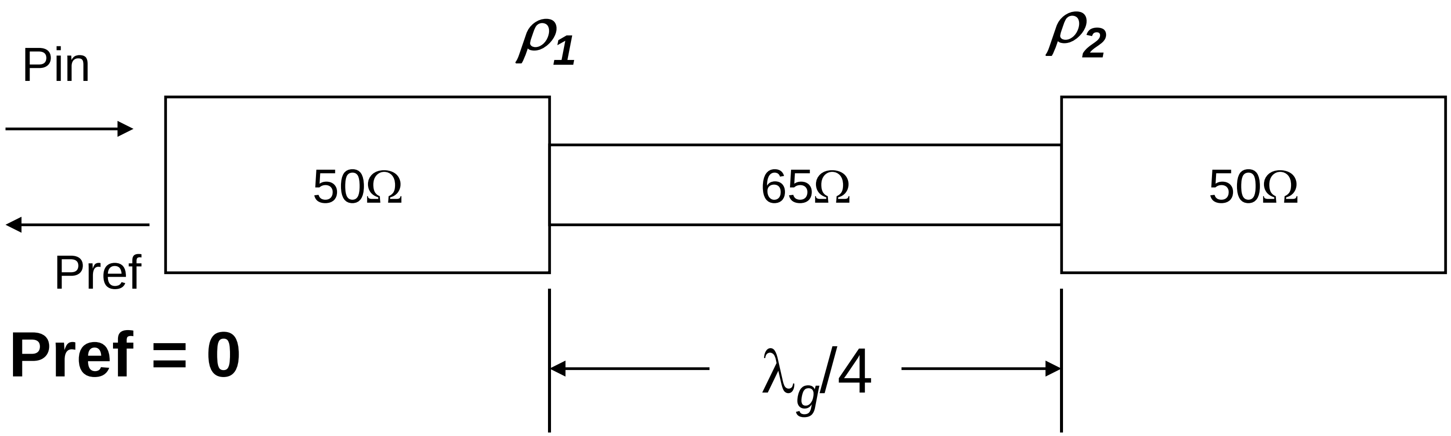
What is Zo of a line that has W=0.03mm and H=0.1mm

65Ω



What is return loss of this structure on 0.1mm thick GaAs
Assume that the line on the right has infinite length.

Reflections at Multiple Interfaces



Pref = 0

$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$\rho_2 = -\rho_1$$

Splitter

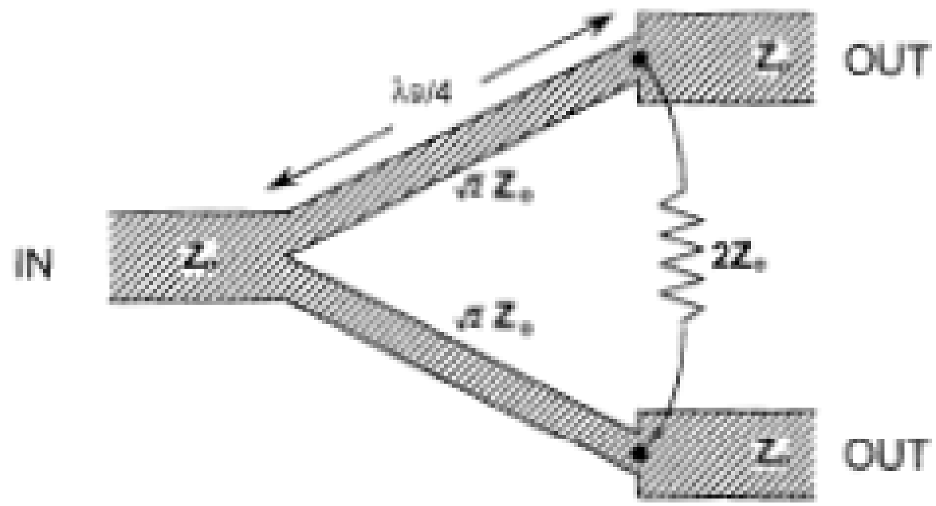


Figure 3.20 Microstrip layout of the Wilkinson power splitter

First MMIC Layout

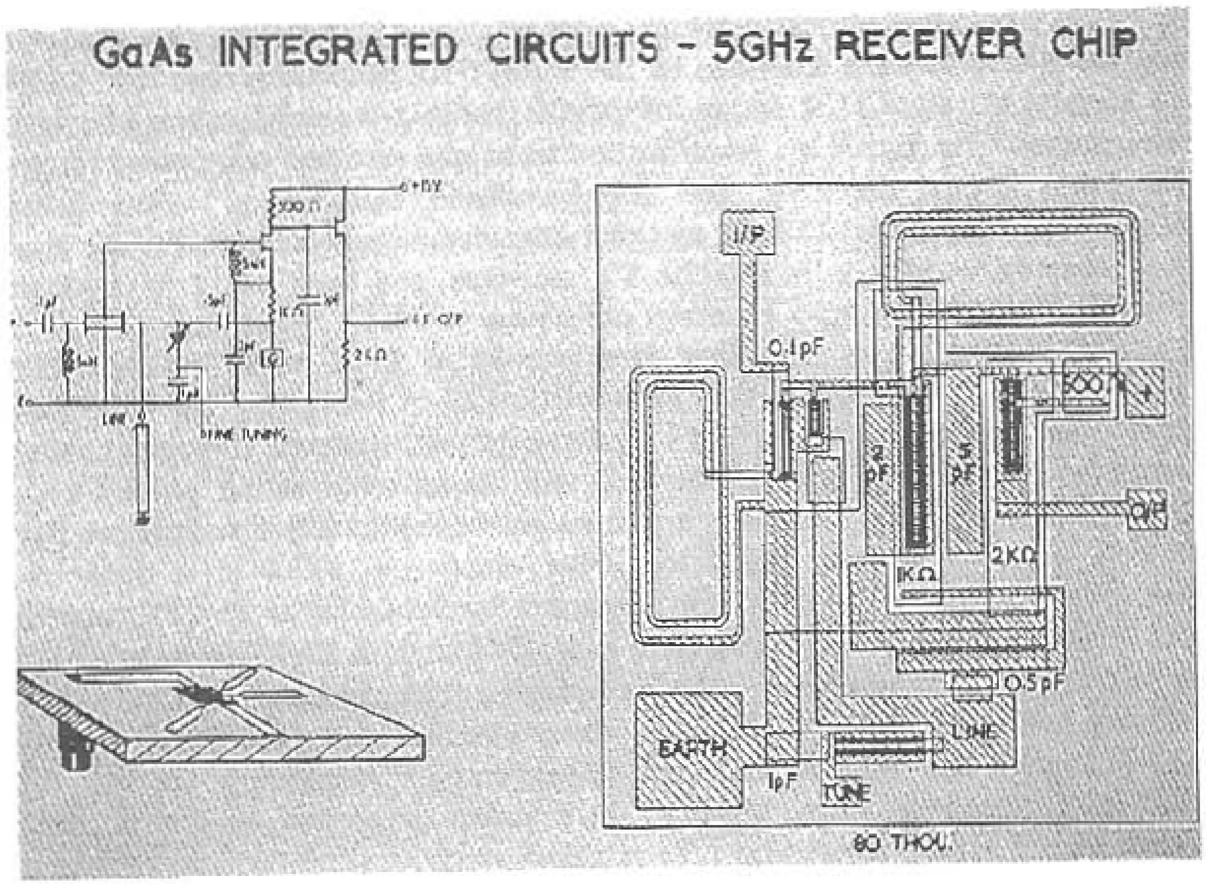


Figure 1.2 Pioneering MMIC layout in 1969
(Courtesy of Marconi Caswell Ltd)