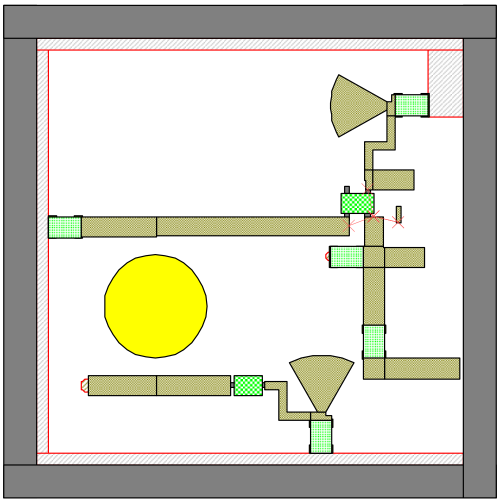
Radiofrequency Electronic Systems

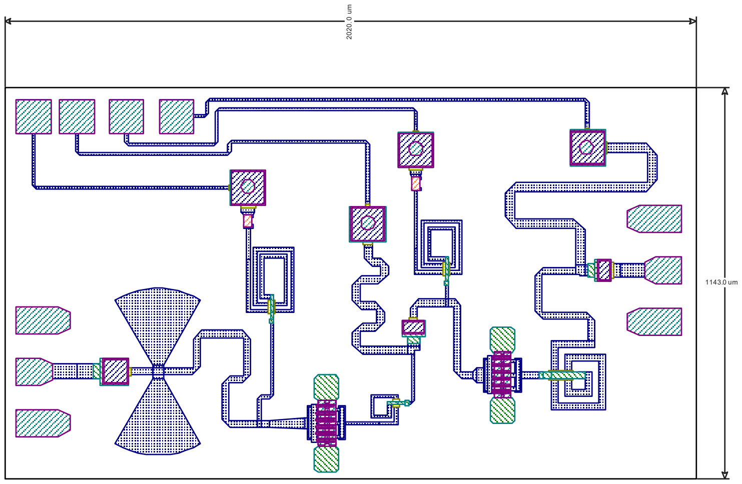
Technology for radiofrequency integrated circuits

Prof. Stefano Pisa

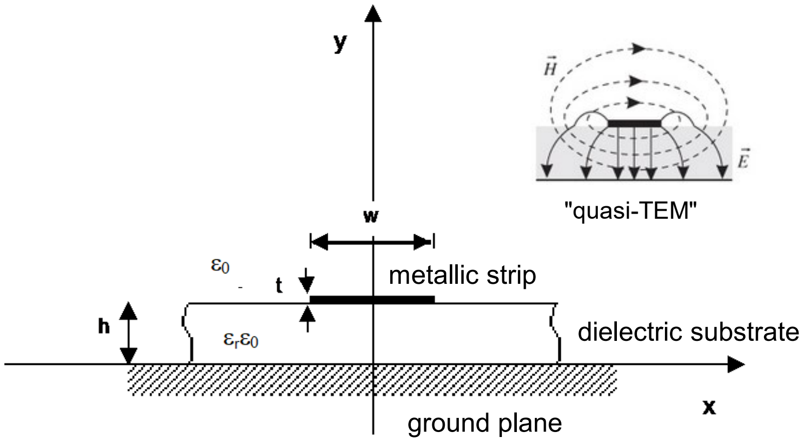
Hybrid Circuit or Microwave integrated Circuit (MIC)



Monolitic MIC (MMIC)
(Two stage amplifier)



Microstrip line

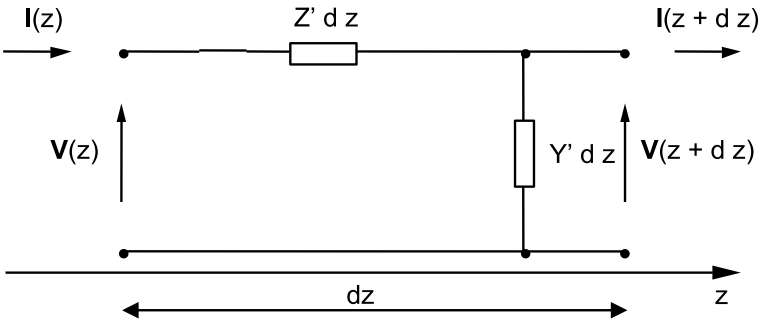


Substrates

material	surface finish (μm) roughness	$10^4 \cdot \tan\delta$ (10 GHz)	ε_r	Thermal cond. (W/cm^2/°C)
Alumina 99.5 %	2 - 8	1 - 2	10	0.37
Alumina 96 %	20	6	9	0.28
Alumina 85 %	50	15	8	0.20
Sapphire	1	1	9.4	0.4
Glass	1	20	5	0.01
Polyolefin	1	1	2.3	0.001
Duroid (Roger)	1	5 - 60	2 -10	0.0026
Quartz	1	1	3.8	0.01
Beryllium	2 - 50	1	6.6	2.5
GaAs (high-res)	1	6	13	0.3
Silicon (high-res)	1	10 -100	12	0.9
Air (dry)	-	≈ 0	1	0.00024

$$\tan\delta = \varepsilon'' / \varepsilon'$$

Transmission line model primary constant



$Z' = R' + j\omega L'$

impedance per unit of length

$Y' = G' + j\omega C'$

admitatnce per unit of length

Secondary constants

$$\gamma = \alpha + j\beta = \sqrt{Z'Y'} = \sqrt{(R'+j\omega L')(G'+j\omega C')}$$

Propagation constant

$$Z_0 = Z_{0r} + jZ_{0j} = \sqrt{\frac{Z'}{Y'}} = \sqrt{\frac{R'+j\omega L'}{G'+j\omega C'}}$$

Characteristic impedance

$$\frac{d^2\mathbf{V}(z)}{dz^2} = \gamma^2\mathbf{V}(z) \qquad \frac{d^2\mathbf{I}(z)}{dz^2} = \gamma^2\mathbf{I}(z)$$

$$\mathbf{V}(z) = \mathbf{V}^+e^{-\gamma z} + \mathbf{V}^-e^{+\gamma z}$$

$$\mathbf{I}(z) = \left(\frac{1}{Z_0}\right)\left(\mathbf{V}^+e^{-\gamma z} - \mathbf{V}^-e^{+\gamma z}\right) = \mathbf{I}^+e^{-\gamma z} - \mathbf{I}^-e^{+\gamma z}$$

Low losses

$$\gamma = \sqrt{R'G' + j\omega C'R' + j\omega L'G' - \omega^2 L'C'} =$$

$$\gamma = \alpha + j\beta \approx \frac{1}{2}\left(\frac{R'}{Z_0} + G'Z_0\right) + j\omega\sqrt{L'C'}$$

$$Z_0 = \sqrt{\frac{Z'}{Y'}} = \sqrt{\frac{R'+j\omega L'}{G'+j\omega C'}}$$

$$Z_0 \approx \sqrt{\frac{L'}{C'}}$$

Microstrip analysis equations

$$\beta=\omega\sqrt{L^{'}C^{'}}=\omega\sqrt{L_0^{'}C^{'}\frac{C_0^{'}}{C_0^{'}}}=\frac{\omega}{c}\sqrt{\frac{C^{'}}{C_0^{'}}}$$

equivalent permittivity

$$Z_0=\sqrt{\frac{L^{'}}{C^{'}}}=\sqrt{\frac{L_0^{'}}{C^{'}}\frac{C_0^{'}}{C_0^{'}}}=\frac{1}{c\sqrt{C_0^{'}C^{'}}}$$

$$\varepsilon_{eff}=\frac{C^{'}}{C_0^{'}}\qquad \begin{array}{ll} w\rightarrow\infty & \varepsilon_{eff}\rightarrow\varepsilon_r \\ w\rightarrow 0 & \varepsilon_{eff}\rightarrow(\varepsilon_r+1)/2 \end{array}$$

$$\beta=\frac{\omega}{c}\sqrt{\varepsilon_{eff}}\qquad \lambda=\frac{2\pi}{\beta}=\frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}\qquad Z_0=\frac{1}{c\,C_0^{'}\sqrt{\varepsilon_{eff}}}$$

Analysis equations
Hammerstad formulas (MWO)

For W/h < 1

$$w_{eff}=\frac{2\pi h}{\ln\left(\frac{8h}{w_{eq}}+0.25\frac{w_{eq}}{h}\right)}$$

$$\varepsilon_{eff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[\left(1+\frac{12h}{w_{eq}}\right)^{-1/2}+0.041\left(1-\frac{w_{eq}}{h}\right)^{2}\right]$$

For W/h > 1

$$w_{eff}=h\left[\frac{w_{eq}}{h}+1.393+0.667\ln\left(\frac{w_{eq}}{h}+1.444\right)\right]$$

$$\varepsilon_{eff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{w_{eq}}\right)^{-1/2}$$

Equivalent width

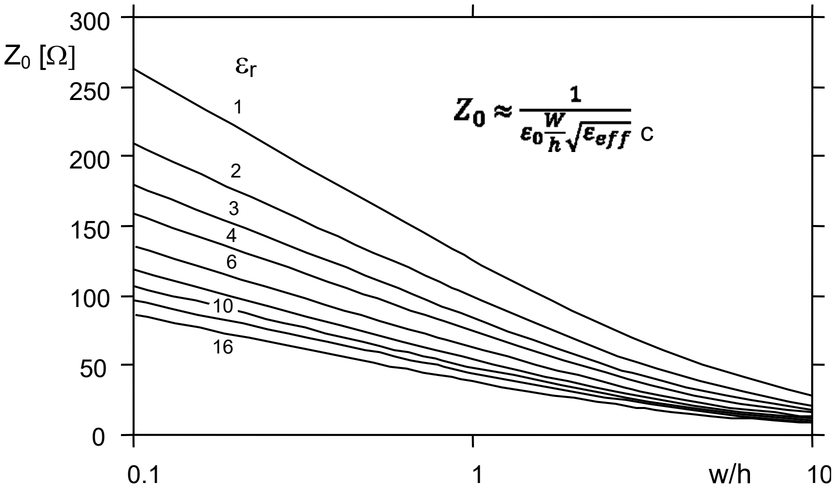
For W/h > 1/(2π)

$$w_{eq} = w + \frac{t}{\pi}\left(1 + \ln\frac{2h}{t}\right)$$

For W/h < 1/(2π)

$$w_{eq} = w + \frac{t}{\pi}\left(1 + \ln\frac{4\pi w}{t}\right)$$

Characteristic impedance (t=0)



Dispersion

Getsinger

$$\varepsilon_{eff}(f)=\varepsilon_r-\frac{\varepsilon_r-\varepsilon_{eff}(0)}{1+G\left(\frac{f}{f_d}\right)^2}$$

$$f_d=\frac{Z_0}{2h\mu_0}$$

$G = 0.6 + 0.009\ Z_0$

$f\uparrow \quad \varepsilon\uparrow$

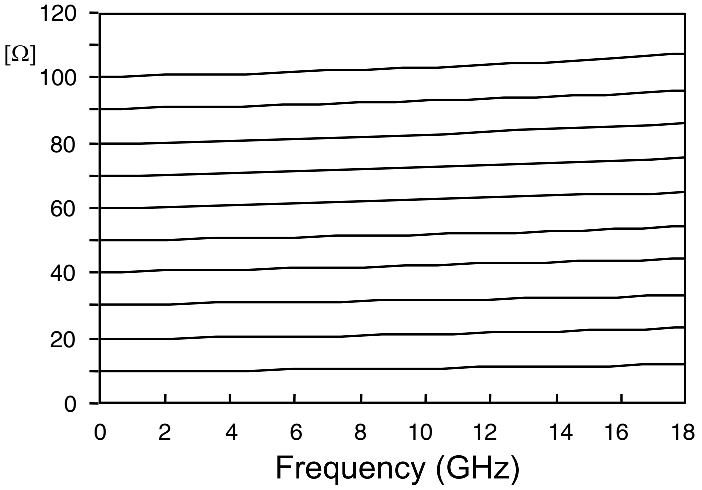
Mehran and Kompa

$$w_{eff}(f)=w-\frac{w-w_{eff}(0)}{1+\frac{f}{f_g}}$$

$$f_g=\frac{c}{2w\sqrt{\varepsilon_r}}$$

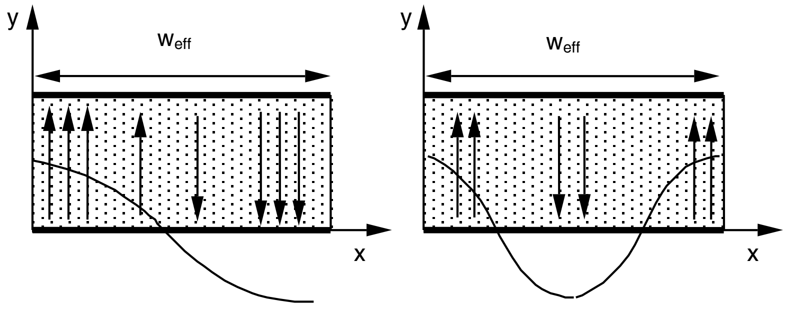
$f\uparrow \quad w\downarrow$

Z_0 - freq.



$\varepsilon_r = 10.1$

Higher order modes



a) b)

$$f_c(TE_{10}) = \frac{c/\sqrt{\varepsilon_{eff}}}{2w_{eff}}$$

$$f_c(TE_{20}) = \frac{c/\sqrt{\varepsilon_{eff}}}{w_{eff}}$$

Synthesis Equations (MWO)

For W/h < 2

$$\frac{w}{h} \cong 4\left[\frac{1}{2}\exp(A) - \exp(-A)\right]^{-1}$$

$$A = \pi\sqrt{2(\varepsilon_r+1)}\,\frac{Z_0}{120\pi} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$$

For W/h > 2

$$\frac{w}{h} \cong \frac{\varepsilon_r-1}{\pi\varepsilon_r}\left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right] + \frac{2}{\pi}\left[B - 1 - \ln(2B-1)\right]$$

$$B = \frac{120\pi^2}{2Z_0\sqrt{\varepsilon_r}}$$

Maximum carried power

Although microstrips are mainly applied in low power systems, they are able to carry average power up to a few kiloWatts.

The upper limit to the average power is essentially set by the thermal conductivity of the substrate which determines how quickly the generated heat can be removed.

The peak power is instead limited by the dielectric strength whose value is about $3 \cdot 10^6$ V / m for the air while it grows in the dielectrics (alumina: $4 \cdot 10^8$ V / m).

Microstrip discontinuity

- Passive linear circuit

- Uniform structures – waveguides
  model -> transmission lines

- Non-uniform structures – discontinuities
  model -> Lumped element circuit

discontinuities desired and unwanted

Qualitative analysis

1. In correspondence of the discontinuities, higher order modes are excited as boundary conditions different from those of the guiding structure must be satisfied

2. The higher order modes do not propagate and are therefore confined to a region around the discontinuity

3. Because these modes store electrical and magnetic energy, their presence can be modeled through a reactive network

4. If the higher order modes are TM, the electrical energy storage is greater than the magnetic one and therefore the equivalent circuit will consist of a capacity. If the modes are TE, magnetic energy storage prevails and the equivalent circuit will consist of an inductance

$$\eta_{TM} = K_z / j\,\omega\,\varepsilon = \alpha_z / j\,\omega\,\varepsilon \qquad \eta_{TE} = j\,\omega\,\mu / K_z = j\,\omega\,\mu / \alpha_z$$

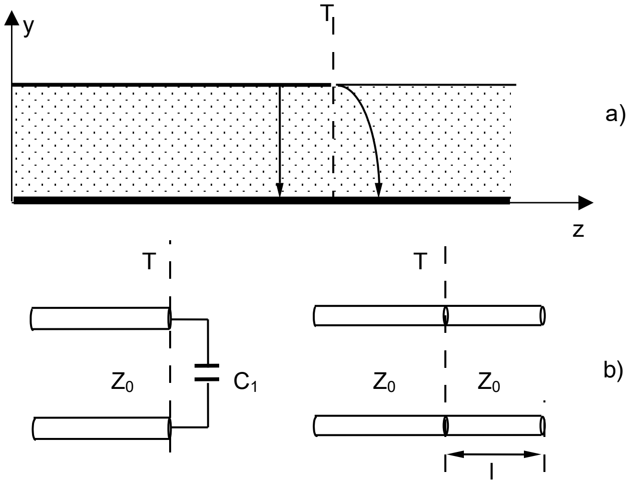
Comments

For discontinuities with reduced longitudinal dimensions the equivalent circuit is generally constituted by a single reactance.
When the longitudinal dimensions are not negligible, a more complex network is required (T or π)

When working with MMIC circuits, since it is impossible to make adjustments, accurate models of discontinuities are required.

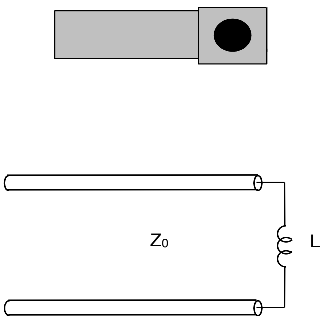
Expressions for reactances in closed form are particularly useful for automatic design software (MWO).

Open end
(unwanted discontinuity)

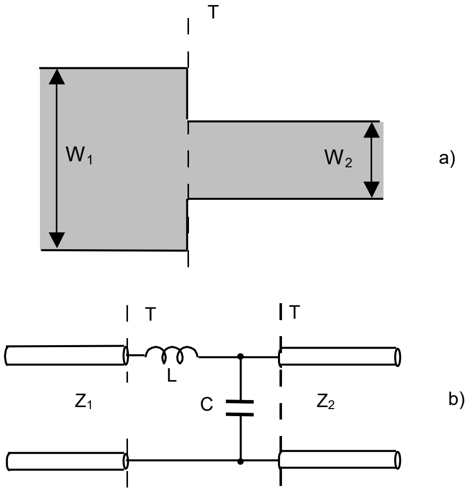


$l = Z_0 C_1 c$

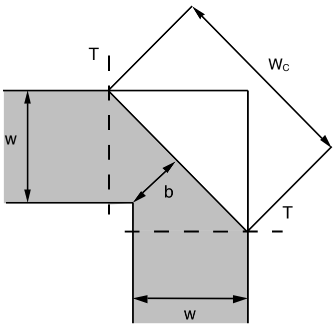
Short
(unwanted discontinuity)



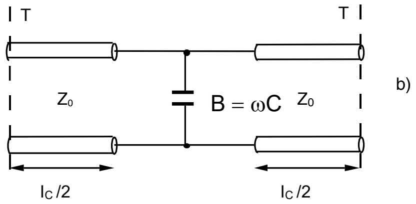
Step in W
(unwanted discontinuity)



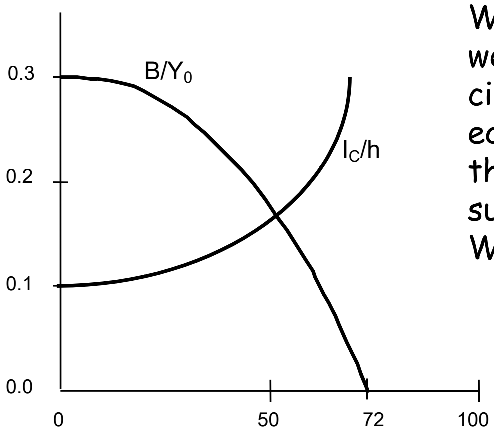
Bend



$$w_c = 2\left[w\sqrt{2} - b\right] = 2\sqrt{2}w\left[1 - \frac{b}{w\sqrt{2}}\right] = 1.8w$$



Chamferred bend



$$\% \text{ smoothing} = \left(1 - \frac{b}{w\sqrt{2}}\right) \times 100$$

With smoothing = 72% we have B = 0 and a circuit lengthening equivalent of 0.3 times the thickness of the substrate and it results $W_C = 1.8W$

Technology MIC (IBRID)

1) Substrates
    - **plastic materials**
    - **ceramic materials**

2) Circuit realization techniques
    - **plastic materials**
        - photolithographic process
        - milling machine
    - **ceramic materials**
        - *photolithographic process*
        - thin film
        - thick film

Plastic Materials (laminates)

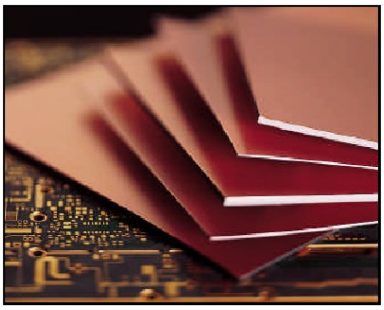
They are sold with copper covers (cladding) on one side or on both sides

Typically, copper is deposited by electrolysis (electrodeposition: ED) on both sides.
For special applications, rolled copper sheets are used which are glued to the dielectric with special insulating resins

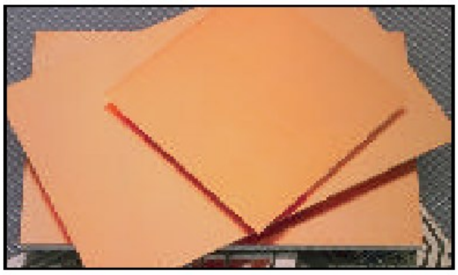
Coverage is expressed in ounces per square foot, (0.5 oz = 0.007 inch = 17 μm)

The dielectrics are available in various thicknesses from 3 to 250 mil
(1 mil = 25.4 μ m) in steps of 5 or 10 mils

Rogers



RO 4003



DUROID

RO 4003 (Rogers)

Plastic resin mixed with ceramic
immersed in a glass-fabric structure

ε_r (dielectric constant at 10 GHz) = 3.38 ± 0.05

H (dielectric thickness) = 508 μm = 0.020" = 20 mill

T (metalization thichness) = 35 μm (1 oz on 2 sides)

Rho (copper/gold resistivity) = 0.7 (copper_res=1.78 $\mu\Omega$/cm)

Tanδ (loss tangent) = 0.0027

1 Inch = 2.54 cm

Ceramic materials (substrates)

Alumina, sapphire and quartz are normally sold as small sheets with or without metallic coating (metallization)

Typical thicknesses range from 10 to 50 mils

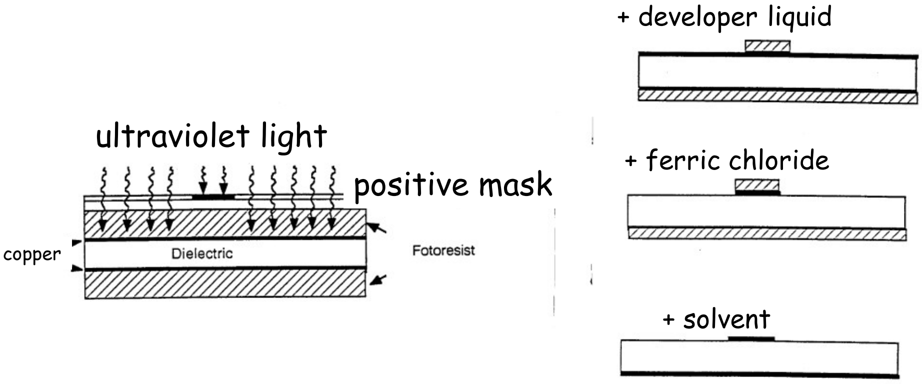
Realization of circuits starting from PLASTIC materials

There are two main techniques for the realization of microstrip circuits from plastic Materials:

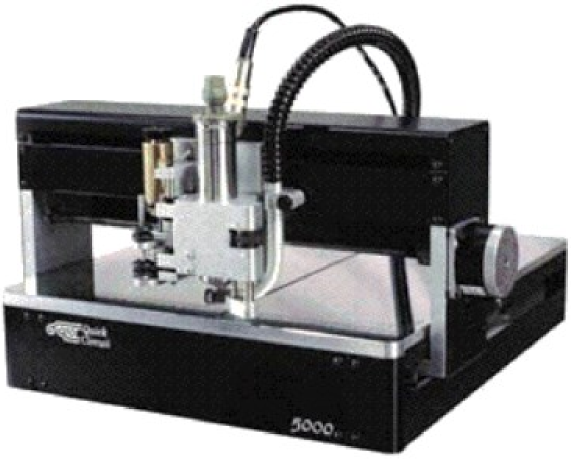
The technique of printed circuits with photographic process

The technique of printed circuit boards with milling machine

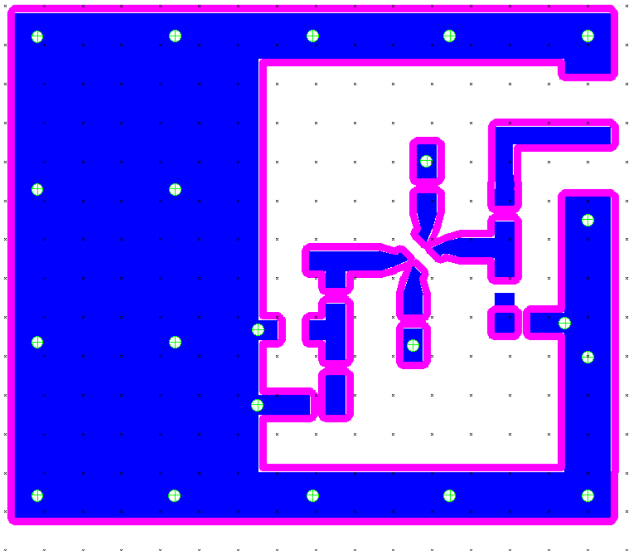
Technique of printed circuit boards with photographic process



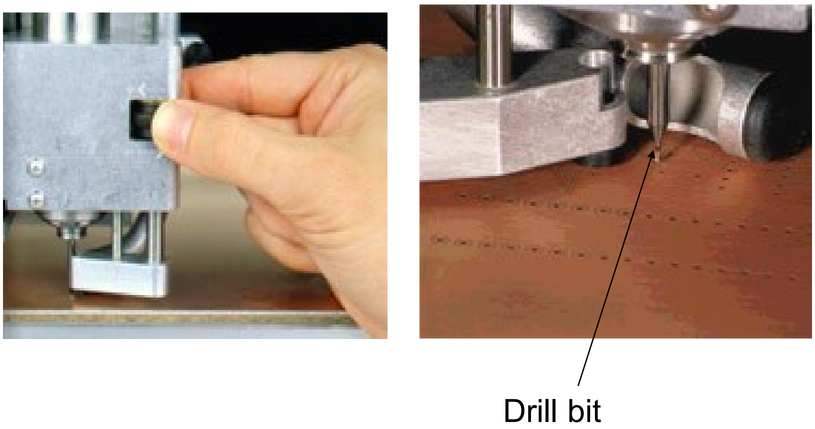
Technique of printed circuit boards with milling machine



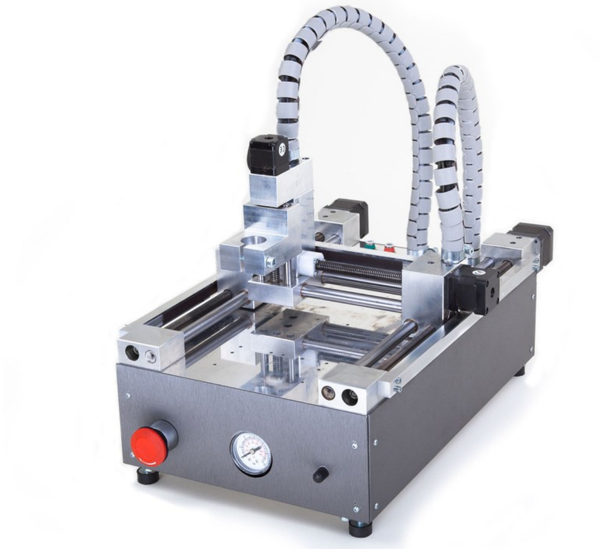
Technique of printed circuit boards with milling machine (ISOPRO)



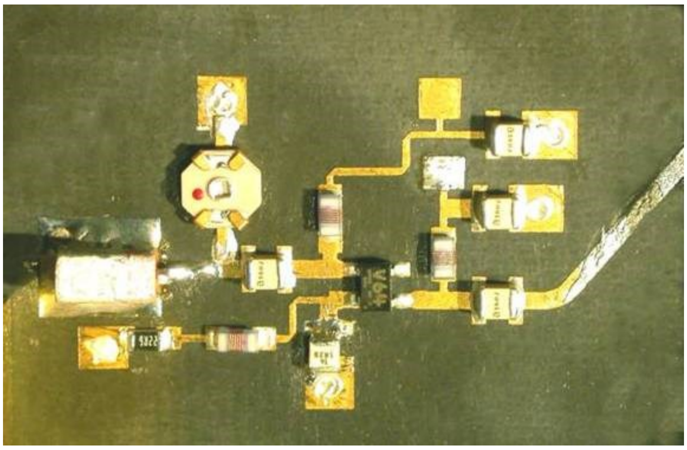
Technique of printed circuit boards with milling machine



CIRQOID (Riga Lettonia)



Hybrid circuits on plastic materials



Realization of circuits starting from CERAMIC materials

There are two main techniques for the realization of microstrip circuits starting from ceramic materials:

The thin film technique

Thick film technique

NB: the photolithographic technique can be used but not the milling machine

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Thin film technique

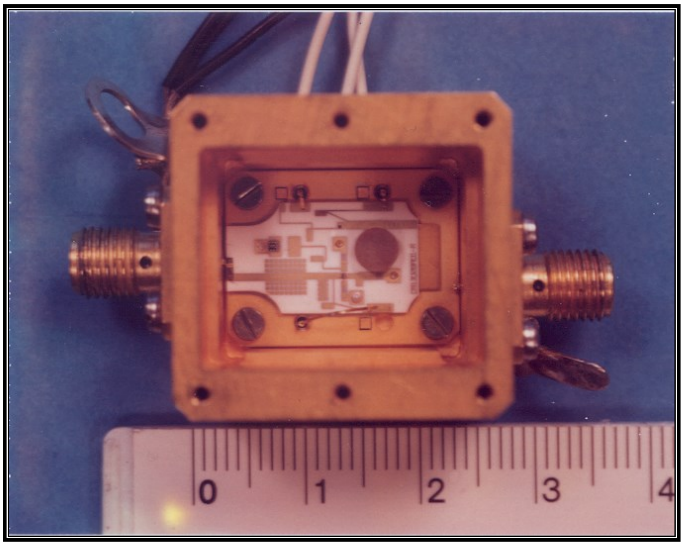
- There are two main techniques for the realization of microstrip circuits starting from ceramic materials:
- Initially a thin layer of chromium (5-20 nm thickness) is deposited on the surface of the dielectric substrate by evaporation or sputtering, which has good mechanical stability and adherence with the substrate itself
- A thin layer of a chrome-copper or chrome-gold mixture is deposited with thicknesses of 5-20 nm
- Finally, the conductive layer (copper or gold) of the desired final thickness is realized by evaporation or sputtering or by electrolytic deposition.
- With a similar approach, resistive or dielectric materials can also be deposited for the realization of resistors and capacitors
- The photographic process is used to define the circuit

Thick film technique

The film technique is often similar to that of screen printing.

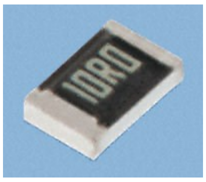
- A thin layer of photoresist is arranged above a rigid frame consisting of a steel mesh with a density varying from 100 to 500 lines per inch
- The mask of the circuit is placed over the frame and exposed to ultraviolet light. The photoresist is removed
- The frame is placed above the substrate and a special paste of gold containing spray is sprayed. The paste is forced with a roller through the mesh so that it covers the areas of the circuit to be made
- The substrate is then placed in an oven and the metal present in the paste is welded to the surface of the dielectric

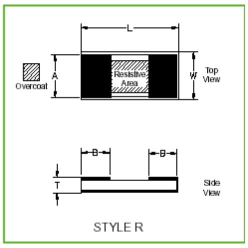
Hybrid circuit on ceramic materials



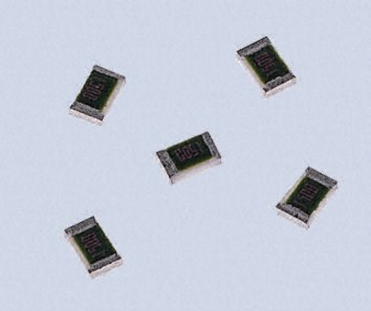
Resistance (SMD)

0805 (2x1.25 mm)





0603 (1.5x0.75 mm)



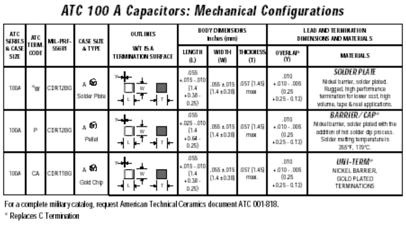
Capacitors ATC 100 A

ATC 100 SERIES PORCELAIN SUPERCHIP® MLCS

These capacitors feature High Q, low ESR/ESL and ultra-stable performance. They are available with an encapsulation option as noted below.

ATC 100 A (size = .055" x .055")

- Capacitance Range 0.1 pF to 100 pF

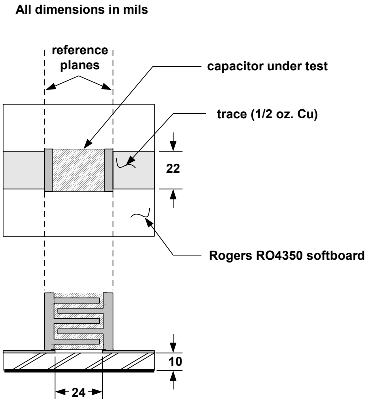


ATC 100 A Capacitors: Mechanical Configurations

ATC SERIES & CASE SIZE	ATC TERM. CODE	MIL-PRF-55681	CASE SIZE & TYPE	OUTLINES W/T IS A TERMINATION SURFACE	BODY DIMENSIONS Inches (mm) LENGTH (L)	WIDTH (W)	THICKNESS (T)	LEAD AND TERMINATION DIMENSIONS AND MATERIALS OVERLAP (Y)	MATERIALS
100A	*W	CDR12BG	A Solder Plate	Y W L T	.055 +.015 -.010 (1.4 +0.38 - 0.25)	.055 ±.015 (1.4 ±0.38)	.057 (1.45) max	.010 +.010 - .005 (0.25 +0.25 - 0.13)	SOLDER PLATE Nickel barrier, solder plated. Rugged, high performance termination for lower cost, high volume, tape & reel applications.
100A	P	CDR12BG	A Pellet	Y W L T	.055 +.025 -.010 (1.4 +0.64 - 0.25)	.055 ±.015 (1.4 ±0.38)	.057 (1.45) max	.010 +.010 - .005 (0.25 +0.25 - 0.13)	BARRIER/CAP* Nickel barrier, solder plated with the addition of hot solder dip process. Solder melting temperature is 355°F, 179°C.
100A	CA	CDR11BG	A Gold Chip	Y W L T	.055 +.015 -.010 (1.4 +0.38 - 0.25)	.055 ±.015 (1.4 ±0.38)	.057 (1.45) max.	.010 +.010 - .005 (0.25 +0.25 - 0.13)	UNI-TERM* NICKEL BARRIER, GOLD PLATED TERMINATIONS

For a complete military catalog, request American Technical Ceramics document ATC 001-818.

* Replaces C Termination



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SMT Products

RF Chip Inductors

0302CS Chip Inductors
Inductance: 0.67 nH – 34 µH
35 values (10 of each)
Kit C170 $90 (5% tolerance)

0402CS Chip Inductors
Inductance: 1 nH – 10 nH
21 values (20 of each)
Kit C128A $55 (5% tolerance)
Kit C128A-2 $75 (2% tolerance)
Inductance: 11 nH – 68 nH
22 values (20 of each)
Kit C128B $55 (5% tolerance)
Kit C128B-2 $75 (2% tolerance)

0402PA High Current Chip Inductors
Inductance: 0.78 nH – 8.2 µH
7 values (10 of each)
Kit C173 $40 (5% tolerance)

0603CS Chip Inductors
Inductance: 1.6 nH – 30 nH
25 values (10 of each)
Kit C124A $60 (5% tolerance)
Kit C124A-2 $80 (2% tolerance)
Inductance: 33 nH – 390 nH
22 values (10 of each)
Kit C124B $60 (5% tolerance)
Kit C124B-2 $80 (2% tolerance)

0603HC Chip Inductors
Inductance: 1.6 nH – 24 nH
11 values (10 of each)
Kit C139 $40 (5% tolerance)

0603LS Chip Inductors
Inductance: 47 nH - 10,000 nH
29 values (10 of each)
Kit C147 $70 (5% tolerance)

0604HQ High Q Chip Inductors
Inductance: 1.15 nH – 10.4 nH
7 values (10 of each)
Kit C151 $40 (5% tolerance)

0805CS Chip Inductors
Inductance: 2.8 nH – 820 nH
37 values (10 of each)
Kit C103 $95 (5% tolerance)
Kit C103-2 $115 (2% tolerance)

0805HQ Chip Inductors
Inductance: 2.5 nH – 51 nH
12 values (10 of each)
Kit C125 $40 (5% tolerance)

0805HT Chip Inductors
Inductance: 1.8 nH – 500 nH
27 values (10 of each)
Kit C121 $70 (5% tolerance)

0805LS Chip Inductors
Inductance: 0.078 µH – 27 µH
18 values (10 of each)
Kit C154 $45 (5% tolerance)

1008CS Chip Inductors
Inductance: 10 nH – 8200 nH
39 values (10 of each)
Kit C100 $100 (5% tolerance)
Kit C100-2 $120 (2% tolerance)

1008HQ High Q Chip Inductors
Inductance: 3 nH – 100 nH
14 values (10 of each)
Kit C123 $40 (5% tolerance)
Kit C123-2 $60 (2% tolerance)

1008HT Chip Inductors
Inductance: 3.3 nH – 560 nH
26 values (10 of each)
Kit C122 $55 (5% tolerance)

1008LS Chip Inductors
Inductance: 1.2 µH – 10 µH
12 values (10 of each)
Kit C136 $40 (5% tolerance)

1206CS Chip Inductors
Inductance: 3.3 nH – 1.2 µH
31 values (10 of each)
Kit C120 $80 (5% tolerance)

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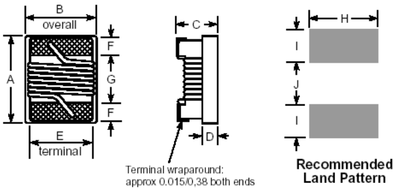
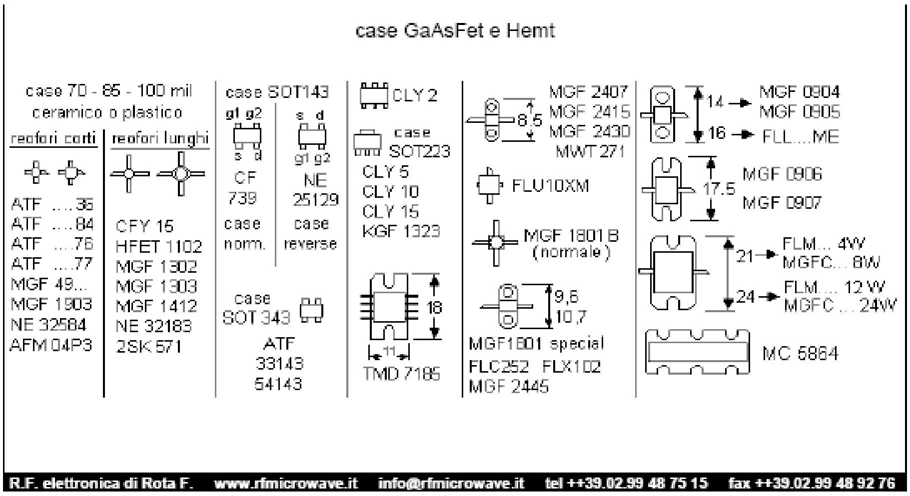
Inductors
SMD o CHIP



Terminal wraparound:
approx 0.015/0,38 both ends

Recommended Land Pattern

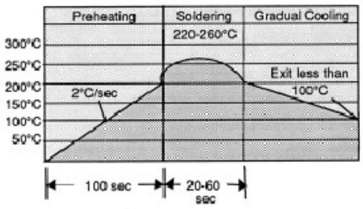
TRANSISTORS



R.F. elettronica di Rota F. **www.rfmicrowave.it** **info@rfmicrowave.it** **tel ++39.02.99 48 75 15** **fax ++39.02.99 48 92 76**

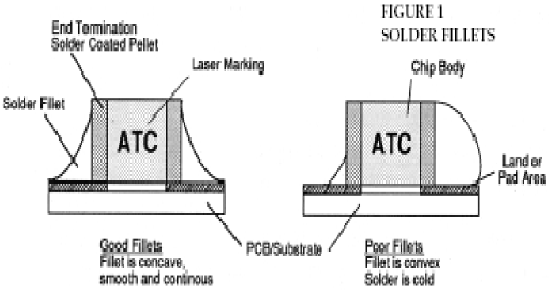
Welding techniques

FIGURE 3 TYPICAL IN PROFILE



Infrared owen
TWS 800

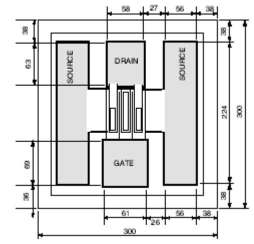
FIGURE 1
SOLDER FILLETS



Transistor chip

CHIP DIMENSIONS (Units in µm)

NE321000 (CHIP)

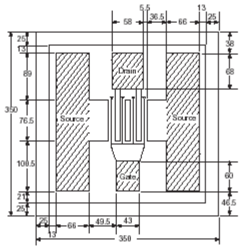


▭ Bonding Pad Area   Chip Thickness: 140 µm typical

Note: All dimensions are typical unless otherwise specified

OUTLINE DIMENSIONS (Units in µm)

CHIP



Thickness = 140 µm

▨ Bonding Area

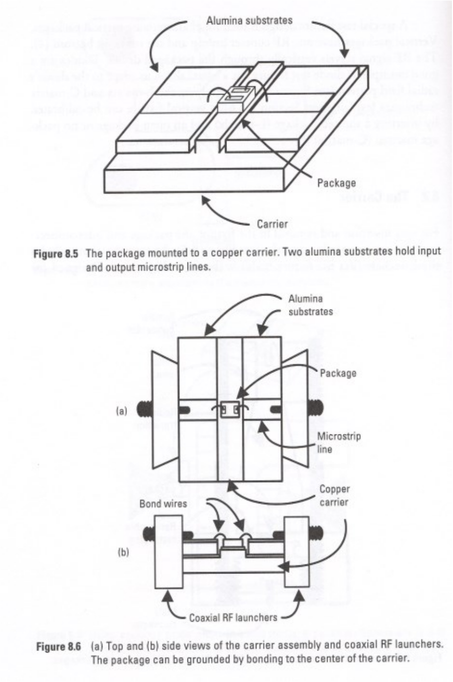
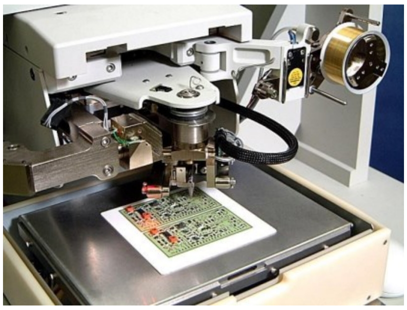


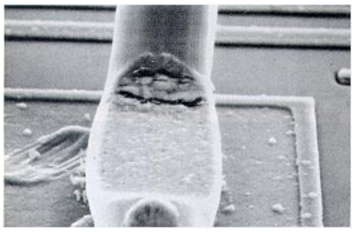
Figure 8.5 The package mounted to a copper carrier. Two alumina substrates hold input and output microstrip lines.

Figure 8.6 (a) Top and (b) side views of the carrier assembly and coaxial RF launchers. The package can be grounded by bonding to the center of the carrier.

Wire bond

Wire bond



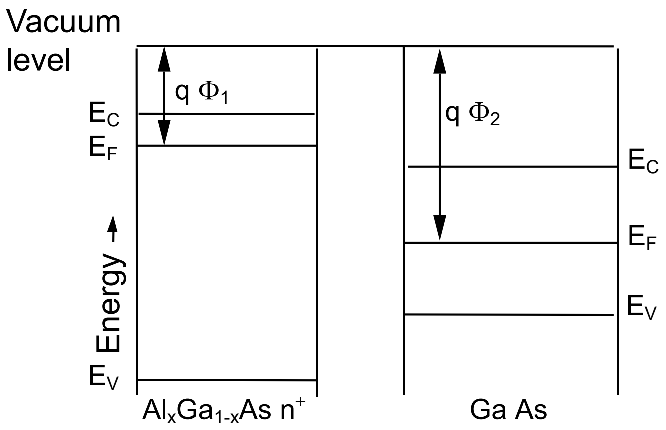


TRANSISTOR

Figure of merit

BJT
MESFET
HBT
HEMT

Heterojunctions



2-DEG

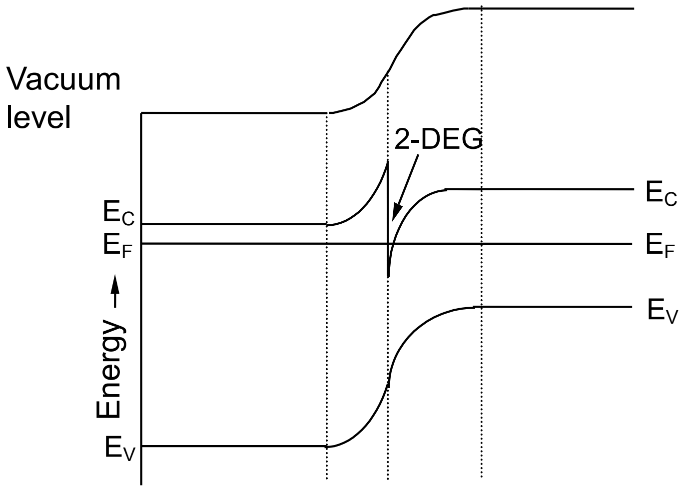


Figure of merit

$$P_m f_T^2 = \frac{1}{X_c}\left(\frac{E_m v_{tm}}{2\pi}\right)^2$$

P_m = maximum power that can be supplied by the transistor

$f_T = 1/2\pi\tau = v_{tm}/2\pi L$ = cutoff frequency of the device

τ = carrier transit time through the active region

L = active region length

v_{tm} = maximum carrier speed

E_m = maximum electric field applicable before breakdown

$Xc = 1/2\pi f_T C_c$ reactance associated with the junction in which breakdown occurs

Typical values

v_{tm} = 0.6x10^7 cm/s, germanium
v_{tm} = 1.0x10^7 cm/s, silicon
v_{tm} = 2x10^7 cm/s, gallium arsenide
v_{tm} = 5.5x10^7 cm/s, 2-DEG of heterojunction

The breakdown electric field is related to the Amplitude of the forbidden band

E_G = 0.66 eV germanium
E_G = 1.12 eV silicon
E_G = 1.43 eV gallium arsenide
E_G = 1.65 eV AlGaAs
E_G = 2.86 eV 6H-SiC
E_G = 3.40 eV GaN

Technology

alongside these general considerations other aspects such as capacity must be taken into account to dissipate material power and status of technology.
With reference to the first point the salient Parameter is the thermal conductivity with respect to which the best material is silicon, while as far as technology still regards the second point the most advanced is that of silicon.

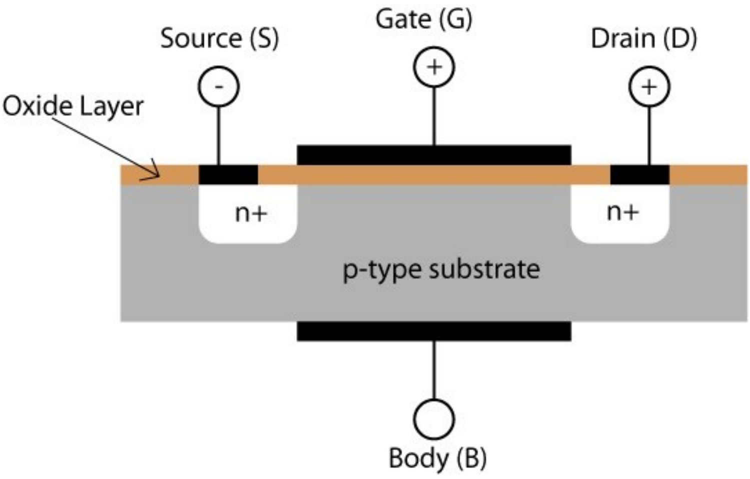
Conclusions

The bipolar transistor (BJT) is the device mostly used up to about 4 GHz

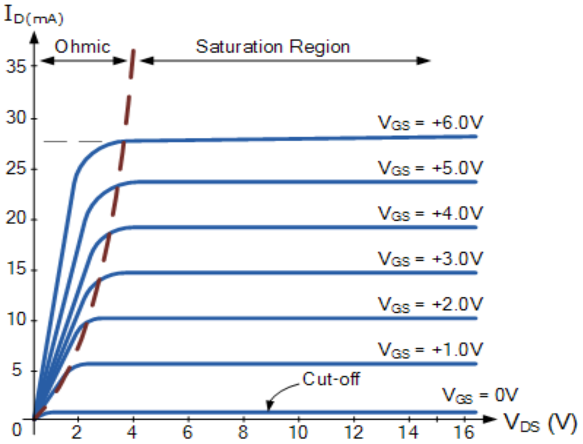
The MESFET dominates between 4 and 20 GHz

For higher frequency applications are increasingly spreading the heterostructure (HEMT).

TRANSISTOR MOS

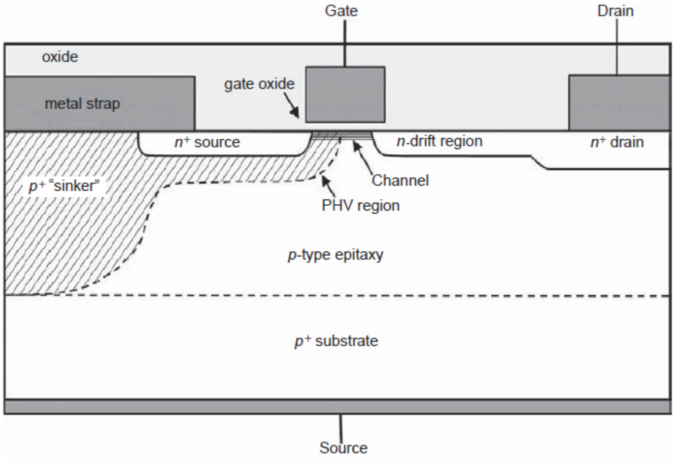


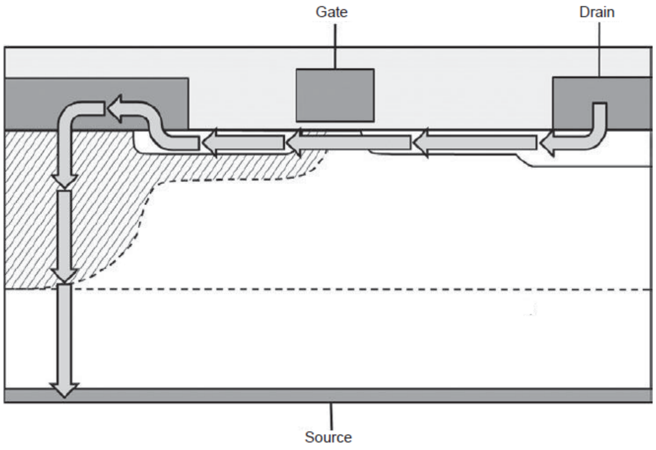
TRANS CHARACTERISTIC MOS enrichment



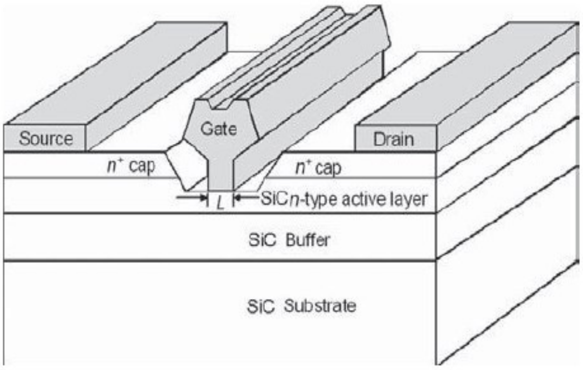
LDMOS

[redacted]

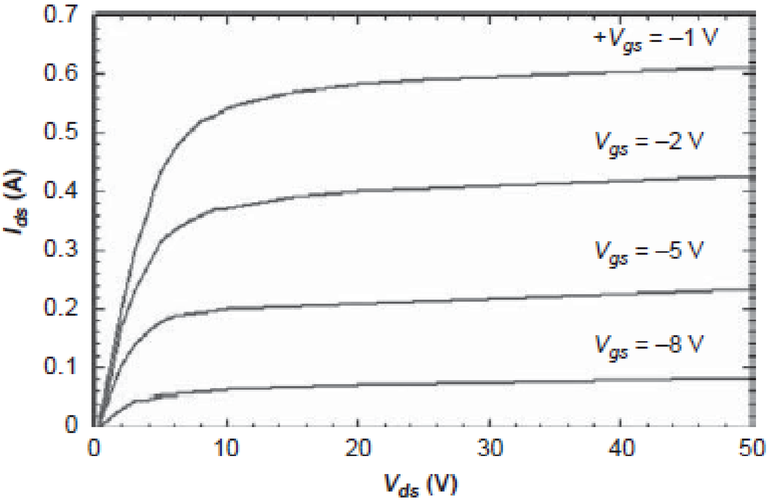



Gate
Drain
Source

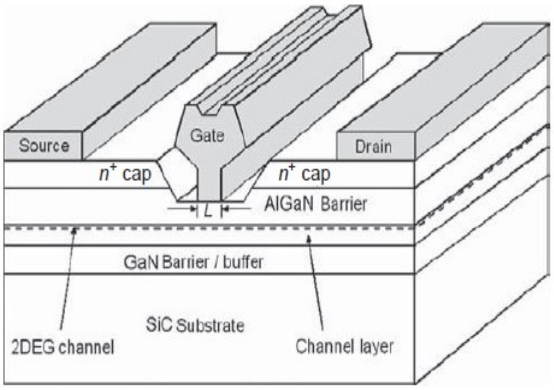
MESFET SiC


Source
Gate
Drain
n^+ cap
n^+ cap
L
SiC n-type active layer
SiC Buffer
SiC Substrate

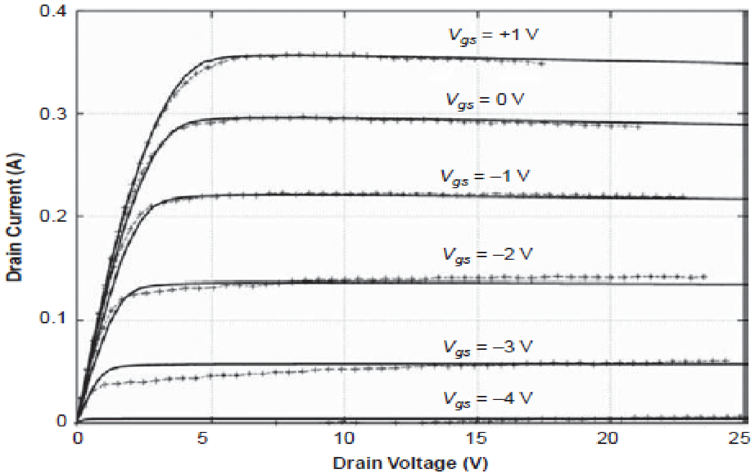
TRANS CHARACTERISTIC MESFET emptying

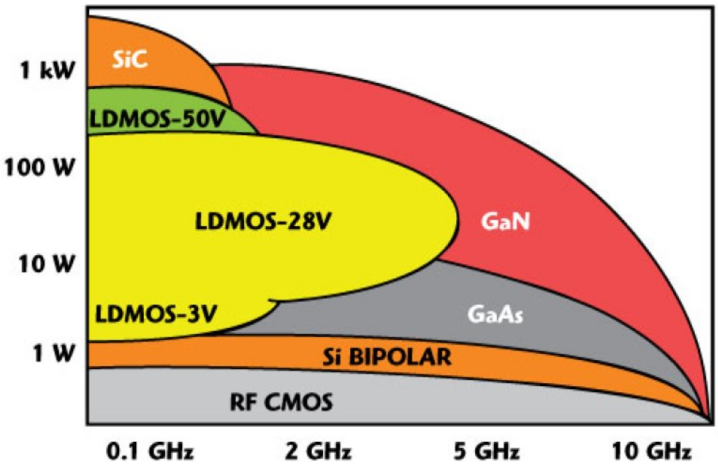


HEMT GaN



TRANS CHARACTERISTIC HEMT
emptying





TRANSFORMERS
and
MIXERS

HF transformers

DIFFER FROM THOSE AT 50 Hz because:

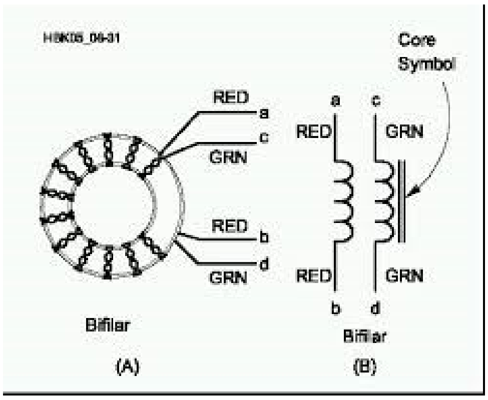
Ferrite is used as a magnetic material

The length of the wires must be a small fraction of the wavelength (<10%)

They operate in the HF band over several decades

They are used as IMPEDANCE ADAPTERS and as BALUN (balanced to unbalanced between antenna and TV cable from unbalanced to balanced at the diode input of a mixer.

HF Transformers
Bifilar windings

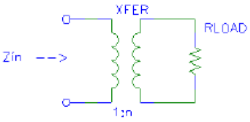


HF transformers
Bifilar windings

$$V_1 = -N_1 \frac{d\Phi}{dt} \qquad V_2 = -N_2 \frac{d\Phi}{dt}$$

$$\longrightarrow \frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{1}{n} \qquad P_{IN} = P_{OUT} \longrightarrow \frac{I_1}{I_2} = -n$$

$$V_2 = -R_{LOAD} I_2$$



$$V_1 = \frac{V_2}{n} = -\frac{R_{LOAD} I_2}{n} = \frac{R_{LOAD} I_1}{n^2} \longrightarrow Z_{IN} = \frac{V_1}{I_1} = \frac{R_{LOAD}}{n^2}$$

HF transformers

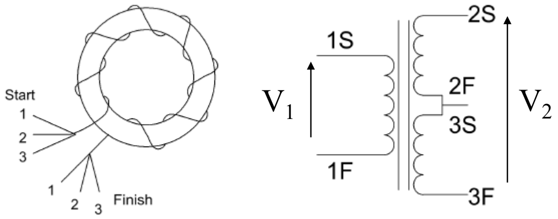


Figure 4. Trifilar winding diagram.

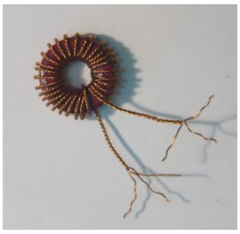


Figure 5. A trifilar wound RF Transformer

HF transformers

$$V_1 = -N_1 \frac{d\Phi}{dt} \qquad V_2 = -2N_1 \frac{d\Phi}{dt}$$

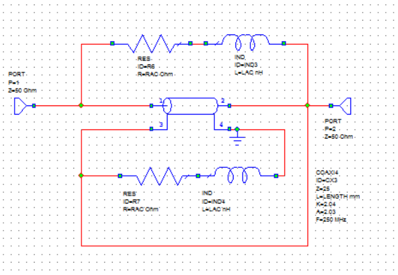
$$\longrightarrow \frac{V_1}{V_2} = \frac{1}{2} \quad da\ P_{IN} = P_{OUT} \longrightarrow \frac{I_1}{I_2} = -2$$

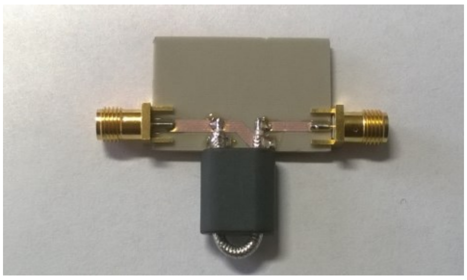
$$V_2 = -R_{LOAD} I_2$$

$$V_1 = \frac{V_2}{2} = -\frac{R_{LOAD} I_2}{2} = \frac{R_{LOAD} I_1}{4} \longrightarrow Z_{IN} = \frac{V_1}{I_1} = \frac{R_{LOAD}}{4}$$

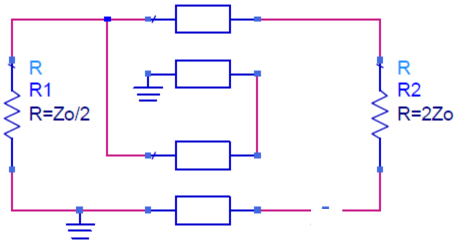
transformer 1:4 (balun) from antenna (300Ω) to coax cable (75 Ω)

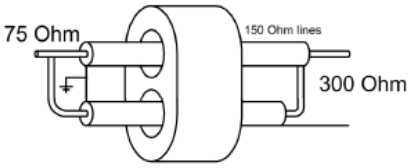
VHF-UHF transformer 1:4





VHF-UHF transformers





VHF-UHF transformers

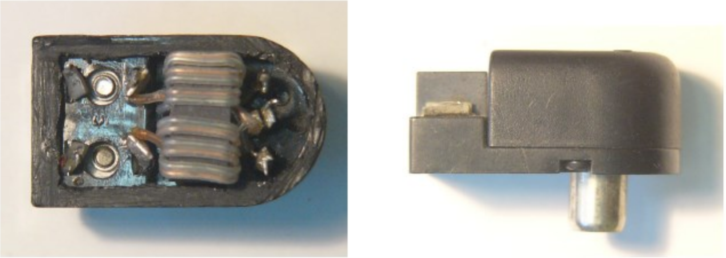
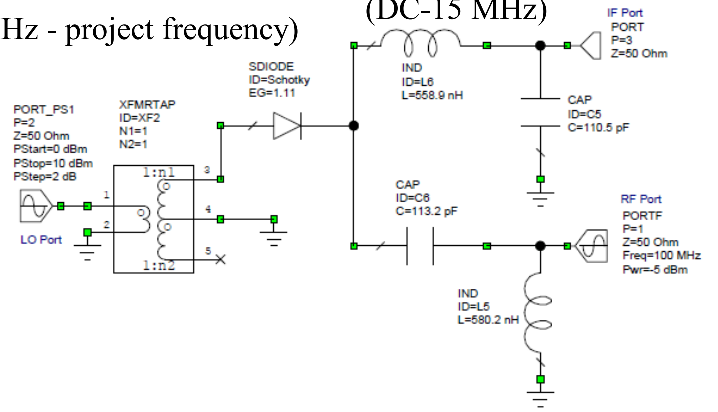


Figure 8. TV Balun using Ferrite RF transformer and transmission line windings.

Mixer with Diplexer



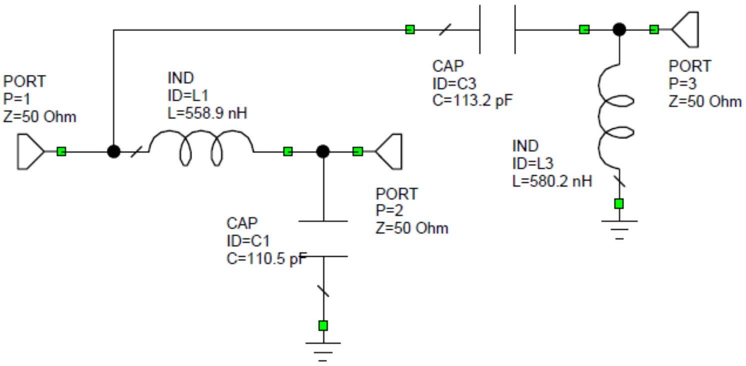
(105 MHz - project frequency)

(DC-15 MHz)

(DC-15 MHz)

Figure 8. Circuit diagram of a single diode mixer as a down-converter.

Diplexer for mixer



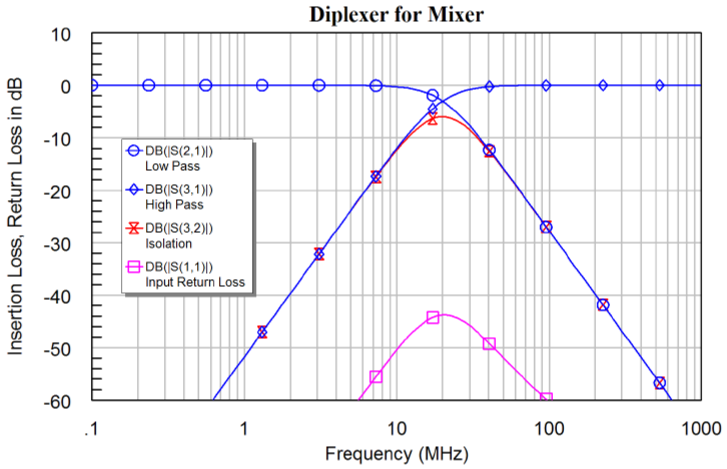


Figure 7. Frequency response of diplexer after optimisation.

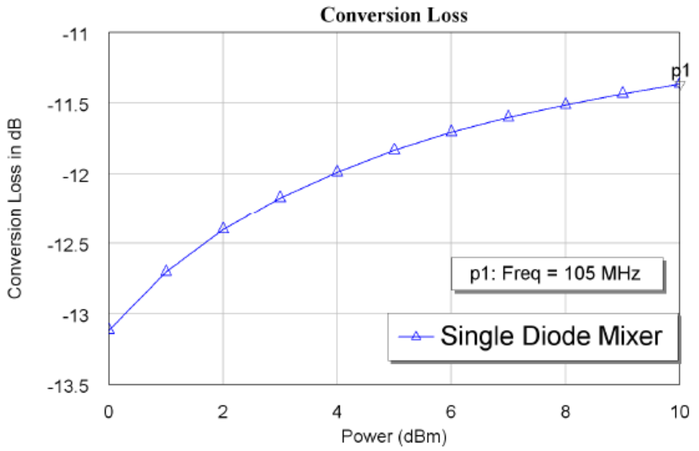


Figure 11. Conversion loss of a single diode mixer.

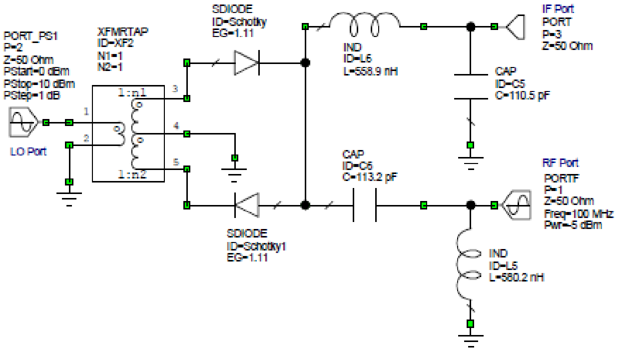


Figure 19. Circuit diagram of a balanced mixer.

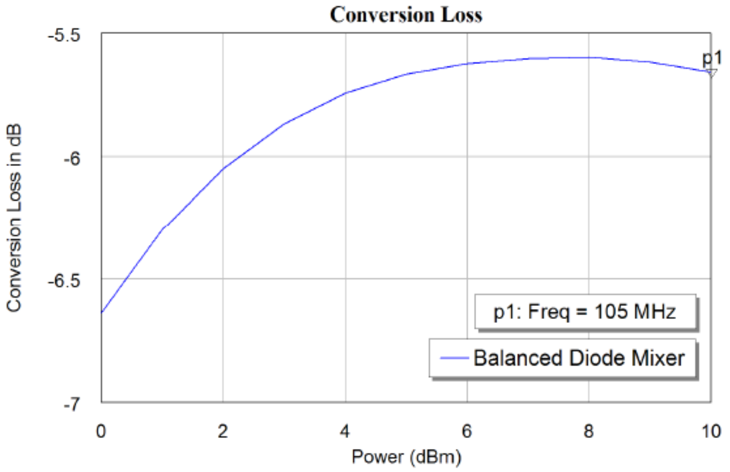


Figure 20. Conversion loss of a balanced diode mixer.

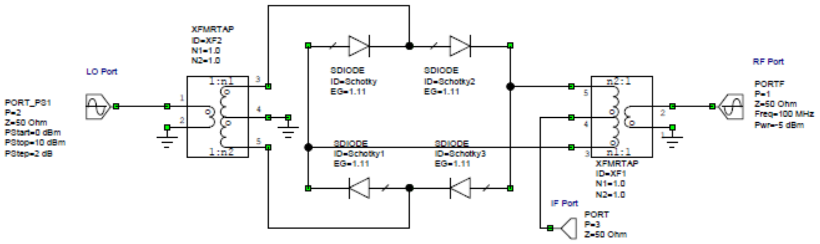


Figure 26. Circuit diagram of a double balanced mixer.

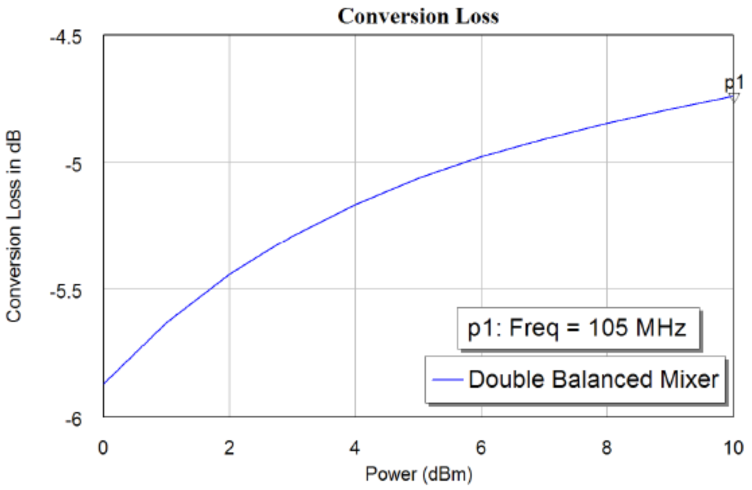


Figure 28. Conversion loss of a double balanced diode mixer.