The New England Chapter

Agile

Microwave Technology Inc

The New England Chapter

"Challenges of Microwave Assembly" by

Jay Chudasama, G.M./President and

Tom Terlizzi, Sr. VP Business Development,

Agile Microwave Technology Inc.

May 2, 2017 at the New England IMAPS Symposium, Boxborough, Mass.

PURPOSE

RF and Microwave Hybrids, “Microwave Integrated Circuits” (MIC), RF and Microwave modules, Monolithic Microwave Integrated Circuits, MMIC all require a unique set of materials and processes necessary to achieve reliable operations in extreme military and commercial environments.

This presentation will examine some of the critical challenges and aspects of “microwave packaging” from a practical perspective and compare to “Low electrical frequency” circuit manufacturing ”

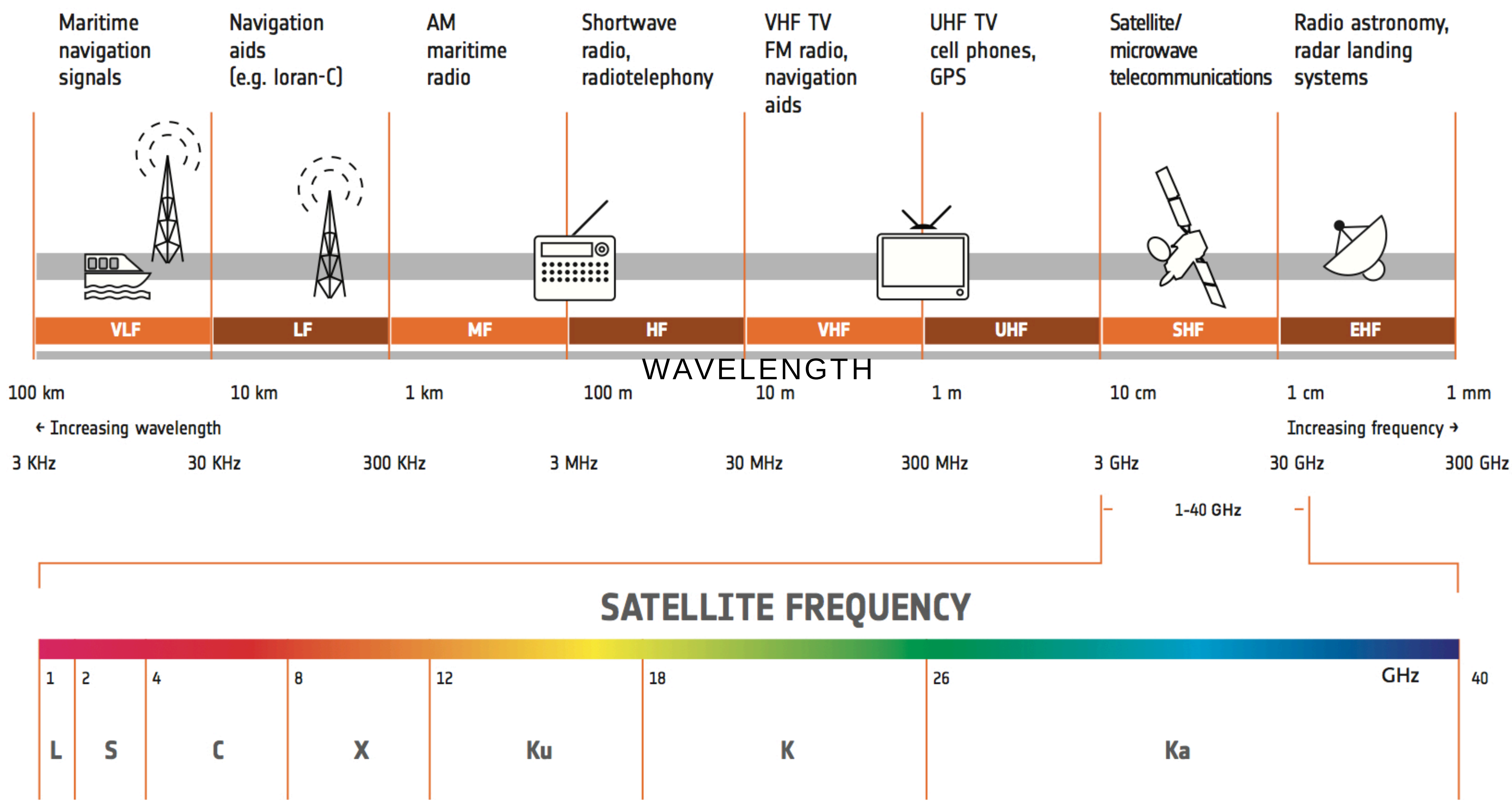
OUTLINE OF CHALLENGES

- Electrical
- Mechanical
- Assembly
- Components
- Packages
- Reliability
- Performance
- Cost

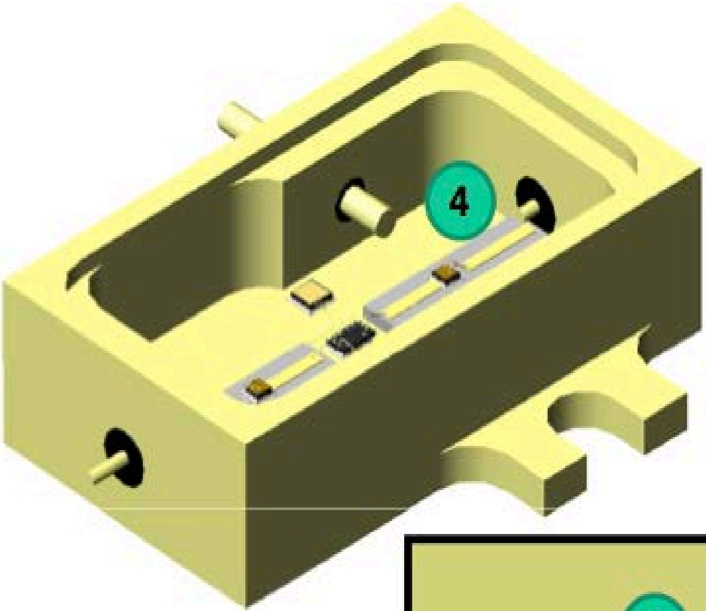
MICROWAVE PACKAGING

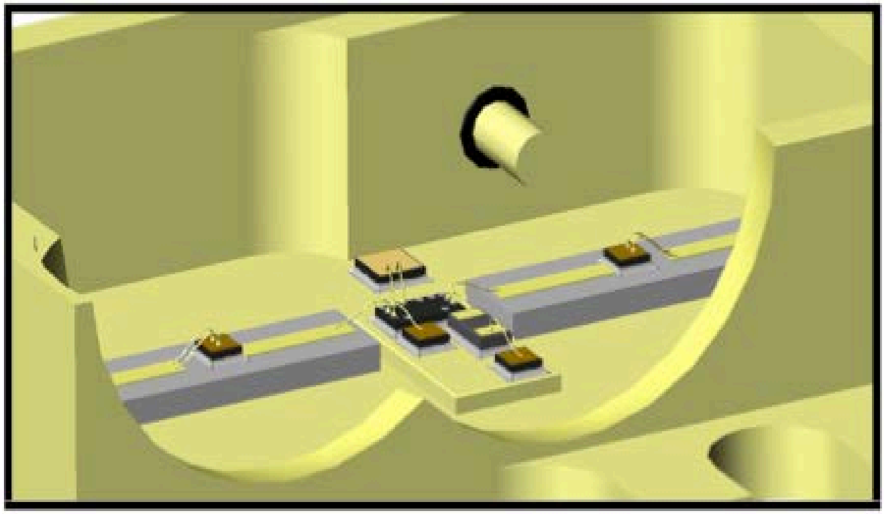
- **PACKAGES**
  - **KOVAR STANDARD AND MACHINED HOUSING**
  - **HTCC/LTCC**
  - **ALUMINUM**
  - **Liquid Crystal Polymer (LCP)**
  - **PWB**
  - **PLASTIC PACKAGES**
- **SUBSTRATES-THICK/THIN FILM, PWB, LTCC , HTCC/LCP/GaAs/Silicon/SiGe/Quartz/Ferrite**
- **ASSEMBLY-DIE ATTACH, WIRE BOND,**
- **SEALING-VISUAL INSPECTION-QUALITY**

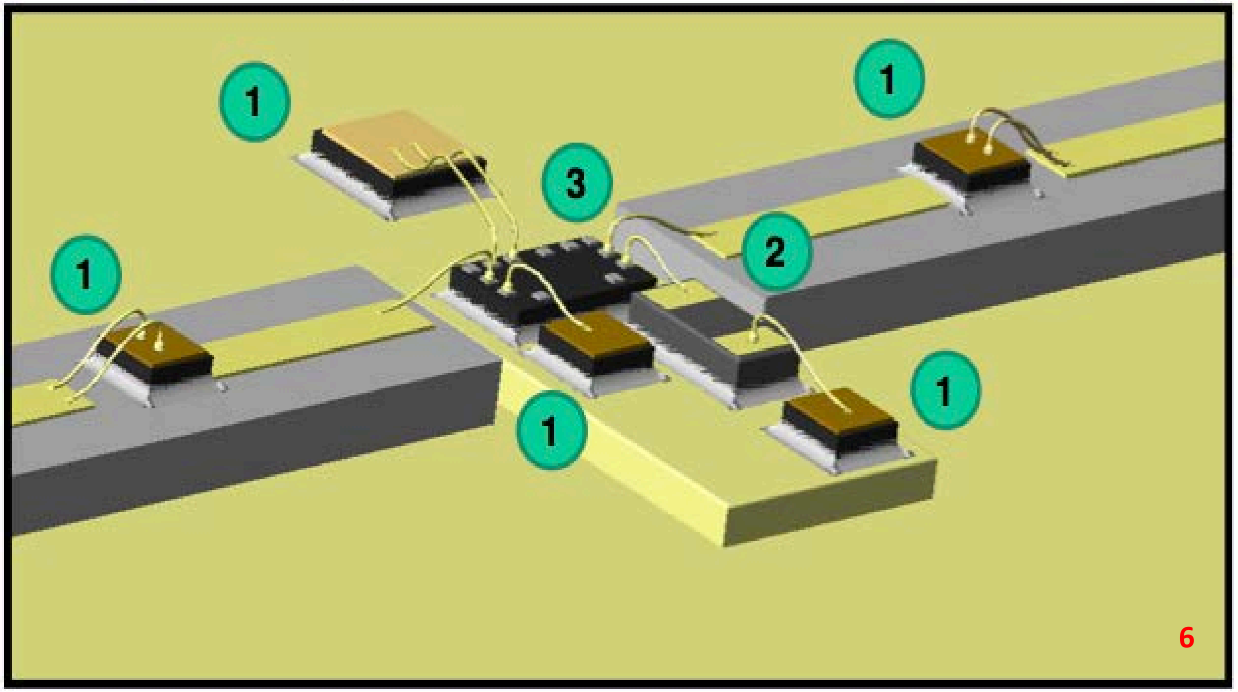
ELECTRICAL


Maritime navigation signals
Navigation aids (e.g. loran-C)
AM maritime radio
Shortwave radio, radiotelephony
VHF TV FM radio, navigation aids
UHF TV cell phones, GPS
Satellite/ microwave telecommunications
Radio astronomy, radar landing systems
VLF
LF
MF
HF
VHF
UHF
SHF
EHF
WAVELENGTH
100 km
10 km
1 km
100 m
10 m
1 m
10 cm
1 cm
1 mm
← Increasing wavelength
Increasing frequency →
3 KHz
30 KHz
300 KHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz
1-40 GHz
SATELLITE FREQUENCY
GHz
1
2
4
8
12
18
26
40
L
S
C
X
Ku
K
Ka

Kovar Housing







LEGEND:

1. CHIP CAPACITOR
2. CHIP RESISTOR
3. GaAs DIE
4. SOLDER PINS

COAX PACKAGE FEED "THRUs"

Coaxial

IMPEDANCE FORMULA   SINGLE COAX LINE 50 OHMS

$$Z = \left(\frac{138}{\sqrt{E}}\right)(\log 10)\left(\frac{D}{d}\right)$$

Z = IMPEDANCE
E = DIELECTRIC CONSTANT
D = HOLE DIAMETER
d = LEAD DIAMETER

Dielectric Constants of some commonly used glasses
7052 - 4.9   7070 - 4.1   9010 – 6.3   AIR = 1 (used as reference)

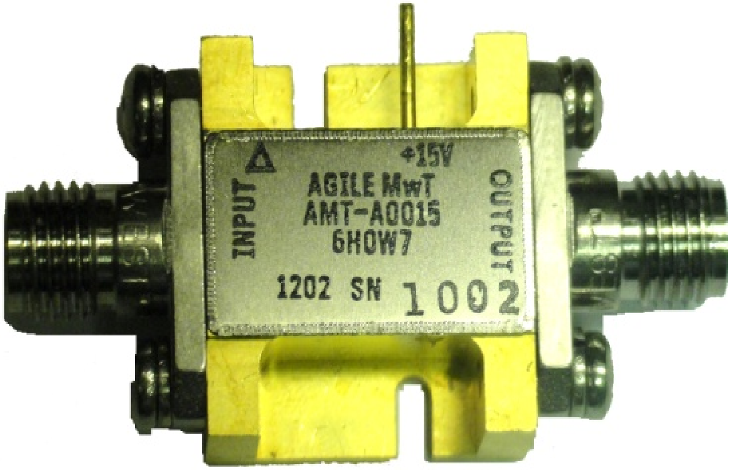
Table 4 - Pin & Hole Diameter Combinations for 50 Ohm Impedance

PIN DIAMETER	7052 GLASS GLASS DIA.	7070 GLASS GLASS DIA.	AIR	9010 GLASS GLASS DIA.
.010/.011	0.063	0.054	0.023	0.081
0.012	0.076	0.065	0.027	0.097
0.015	0.095	0.081	0.034	0.122
0.018	0.114	0.097	0.041	0.146
0.020	0.127	0.108	0.046	0.162

All dimensions are in inches

Kovar Housing

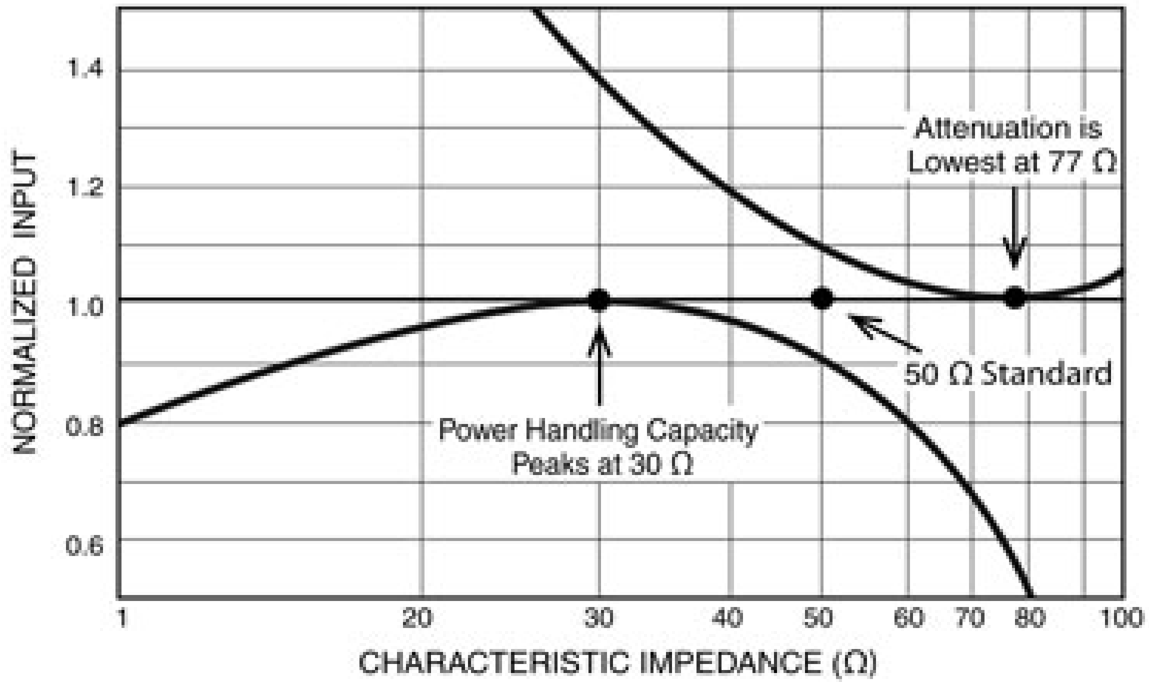
FREQUENCY RELATIONSHIPS		
Frequency	Pin Diameter	Body Diameter
65 GHz	.009"	.068"
42 GHz	.012"	.076"
28 GHz	.015"	.098"
18 GHz	.018"	.110"
8 GHz	.020"	.158"



Transmission Lines and RF Energy

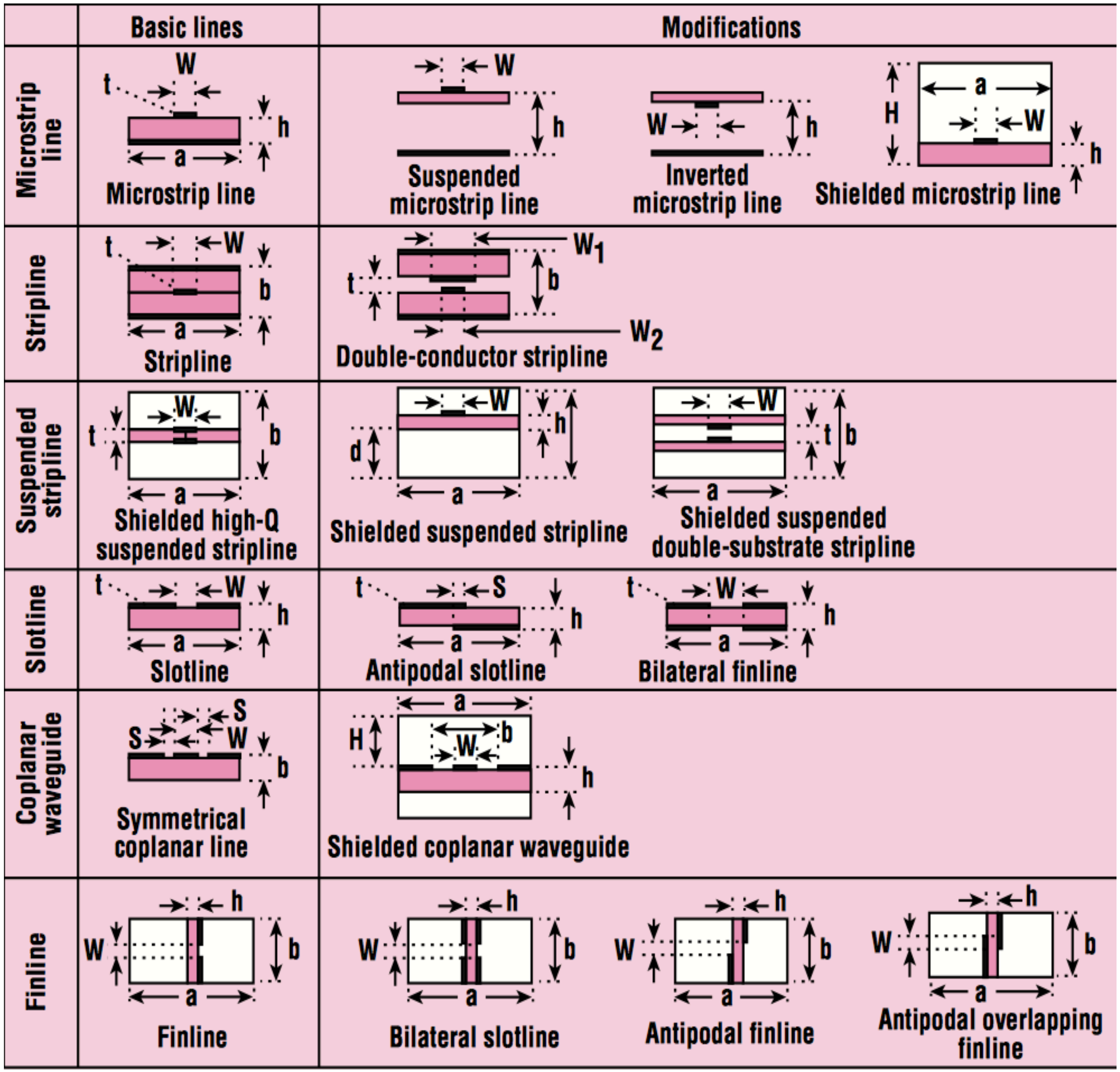
- Why RF circuits are designed with a 50 Ω impedance characteristic impedance
  - A 50 Ω impedance was chosen for high frequency connectors as the best compromise between the optimal impedance for handling power (30 Ω) and lowest attenuation (77 Ω).

30 / 50 / 77 Ω POWER AND ATTENUATION



http://www.microwaves101.com/encyclopedias/why-fifty-ohms

PRINTED TRANSMISSION LINES



PRINTED TRANSMISSION LINES

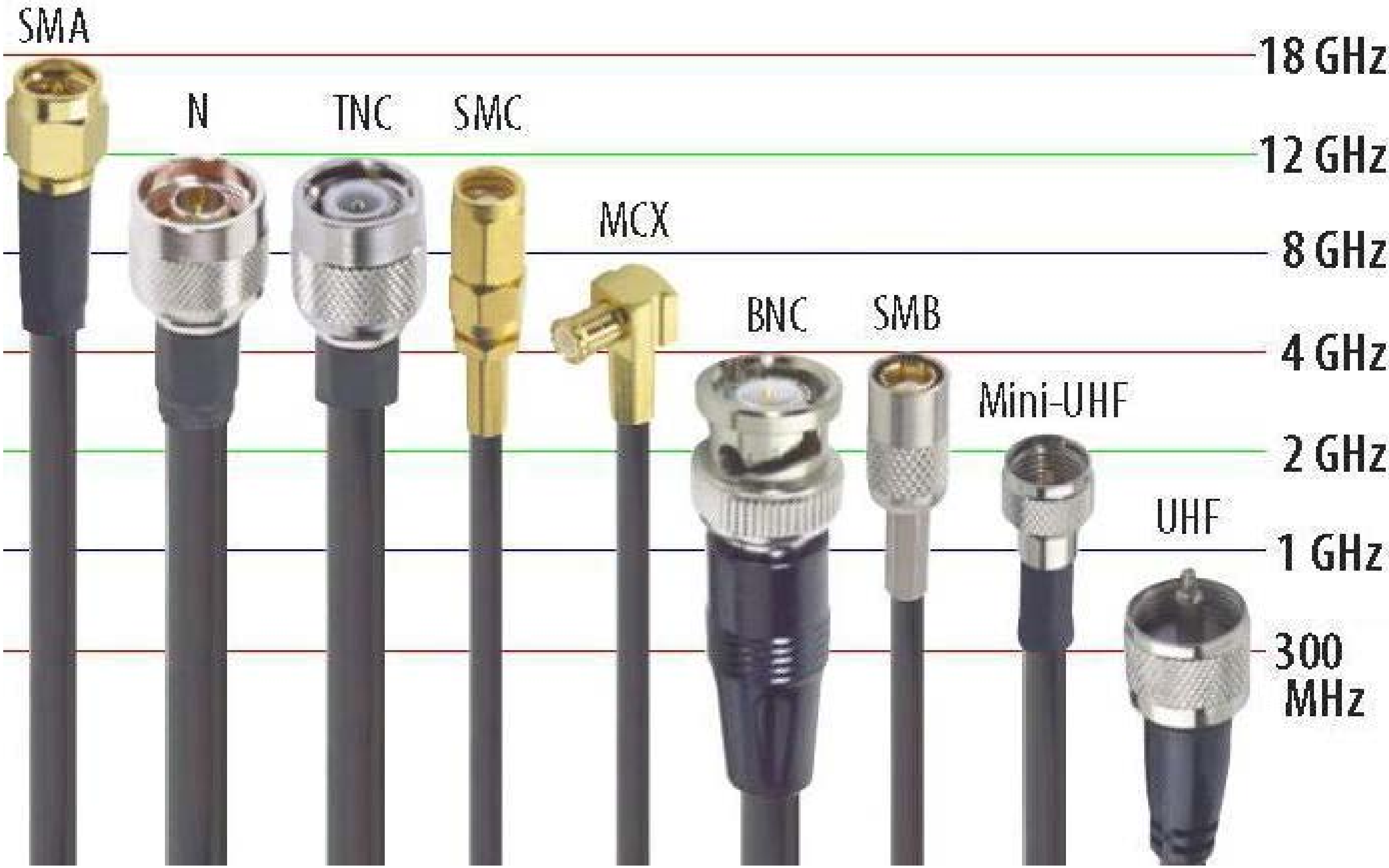
A comparison of various transmission-line types

Transmission line	Q factor	Radiaton	Dispersion	Impedance range	Chip mounting
Microstrip (dielectric) (GaAs, Si)	250 100 to 150	Low High	Low	20 to 120	Difficult for shunt, easy for series
Stripline	400	Low	None	35 to 250	Poor
Suspended stripline	500	Low	None	40 to 150	Fair
Slotline	100	Medium	High	60 to 200	Easy for shunt, difficult for series
Coplanar waveguide	150	Medium	Low	20 to 250	Easy for series and shunt
Finline	500	None	Low	10 to 400	Fair

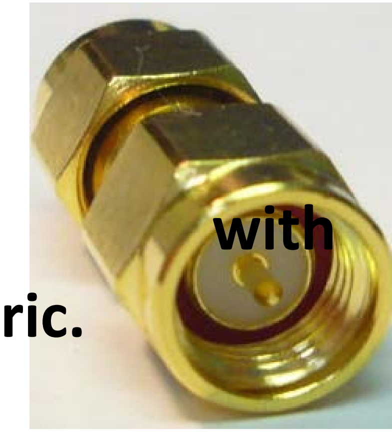
RF CONNECTOR SELECTION CRITERIA

- **FREQUENCY RANGE/RF PERFORMANCE**
- **POWER-VOLTAGE**
- **Mechanicals-size, weight, human factors**
- **Cable to connector-**
  - **type, mounting, assembly, handling**
- **Connectors MIL-PRF-39012.**
- **Adapters/RF connectors MIL-PRF-55339.**
- **High-Reliability connectors MIL-PRF- 31031.**
- **Triaxial RF connectors conform to MIL-PRF-49142**.

RF CONNECTOR SELECTION



SMA CONNECTORS



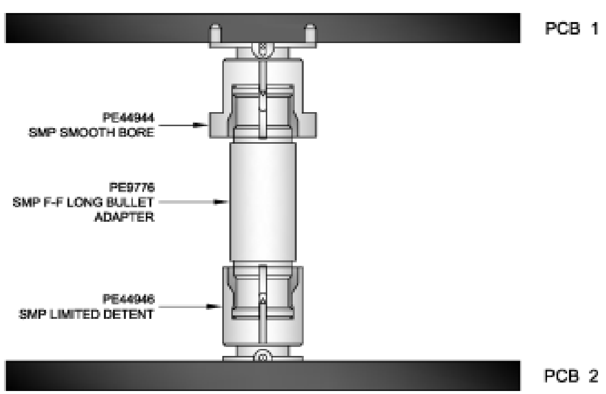
- **SMA –SUB MINIATURE TYPE A**
- **The most popular connector.**
- **4.2 millimeter diameter outer coax, filled with** Teflon™ *PTFE* (polytetrafluoroethylene) **dielectric.**
- **Hundreds of different styles and variation.**
- **Their upper frequency limit is anywhere from 18 to 26 GHz,**

GPO™ (Gilbert Push-On) CONNECTORS

Generic Name	Corning Gilbert	Max. Frequency.
SMP	GPO	26.5 GHz
SMP-M	GPPO	40 GHz
SMP-S	G3PO	65 GHz
tbd	G4PO	60 GHz

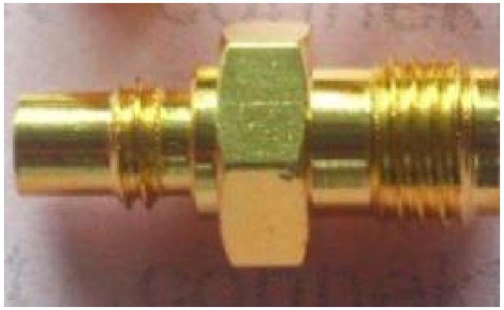
GPO™ CONNECTORS

- **Blind mate - what's that?**
- A blind mate connector is one in which the mating action takes place where you can't see it or feel it.
- A non-threaded inter-lock, and usually, there is some spring action on one connector so that minor misalignments won't cause a jam.



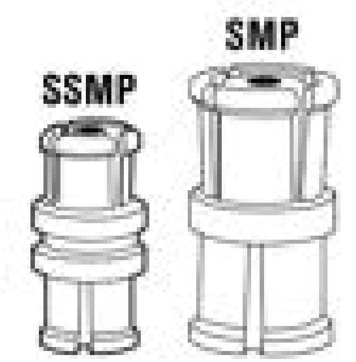
SMB, SMC, MCX CONNECTORS

- SMB (SUB MINIATURE TYPE B)
  – Smaller than SMA and feature a Snap-On coupling and are available in either 50 Ω or 75 Ω
- SMC (SUB MINIATURE TYPE C)
  – Smaller than SMB / Snap-On coupling
- MCX (MICRO COAXIAL)
  – 30% smaller than the SMB.
- SSMP 30% SMALLER THAN SMP
  – BLINDMATE/ TO 65 GHZ



SMC TO SMA

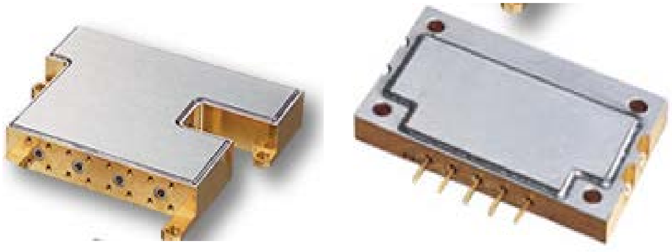
SMA TO MCX



40G Optical Modulator with SSMP® Connector

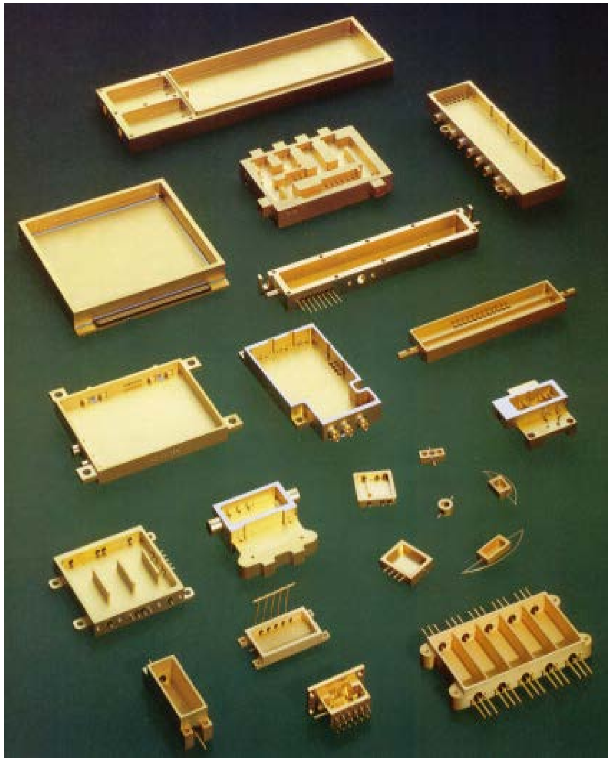
MACHINED KOVAR/ALUMINUM HOUSINGS

- **FEED THRU-SOLDERED OR LASER WELDED**



- **Connection Options**

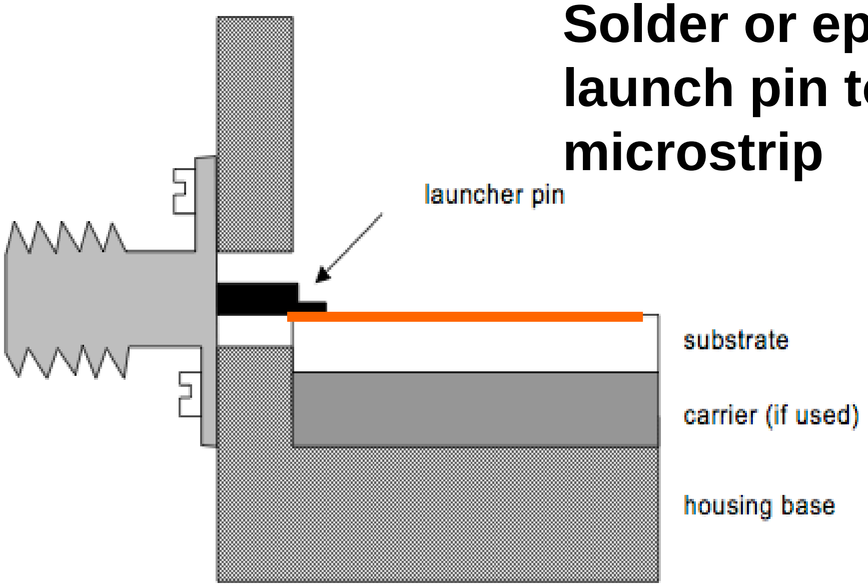
- Direct Glass-to-Metal Seals
- Ceramic-to-Metal Seals
- Stripline / Multi-layer Ceramic Feedthroughs
- SMA Interface/• SSMA Interface
- OSP Interface/• OSSP Interface
- OSM Interface
- Multi-Pin Bulkhead DC Connectors
- (available w/ or w/o jack
  screw mounting)
- Micro "D" Connectors
- Blindmate Connectors



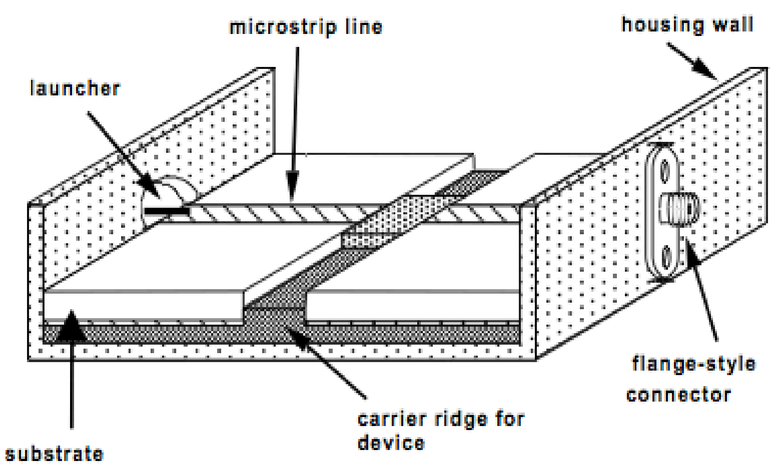
Channels For isolation

RF Connections-Typical MIC Housing

Solder or epoxy the launch pin to the microstrip



Typical coax-microstrip launcher cross-section



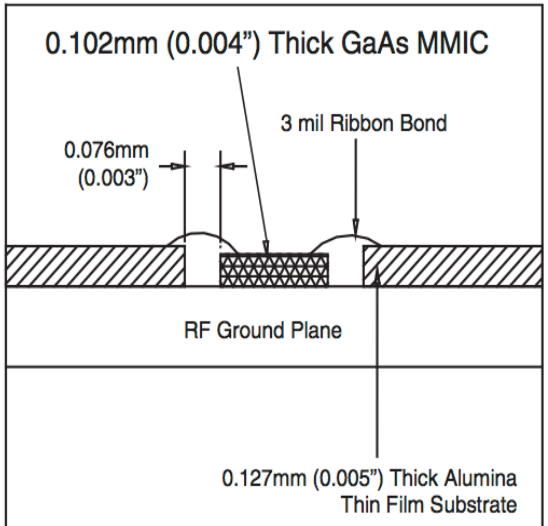


Figure 1.

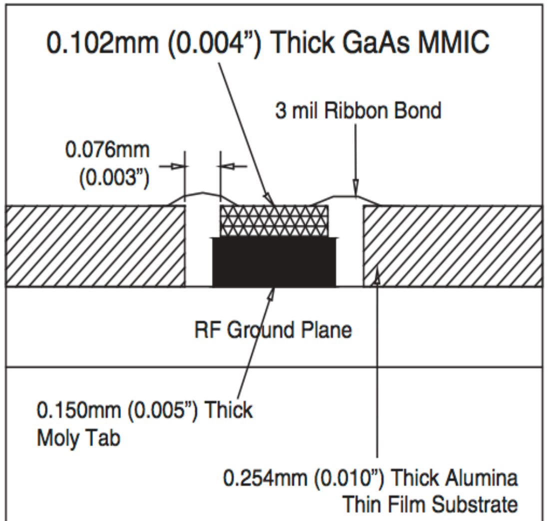
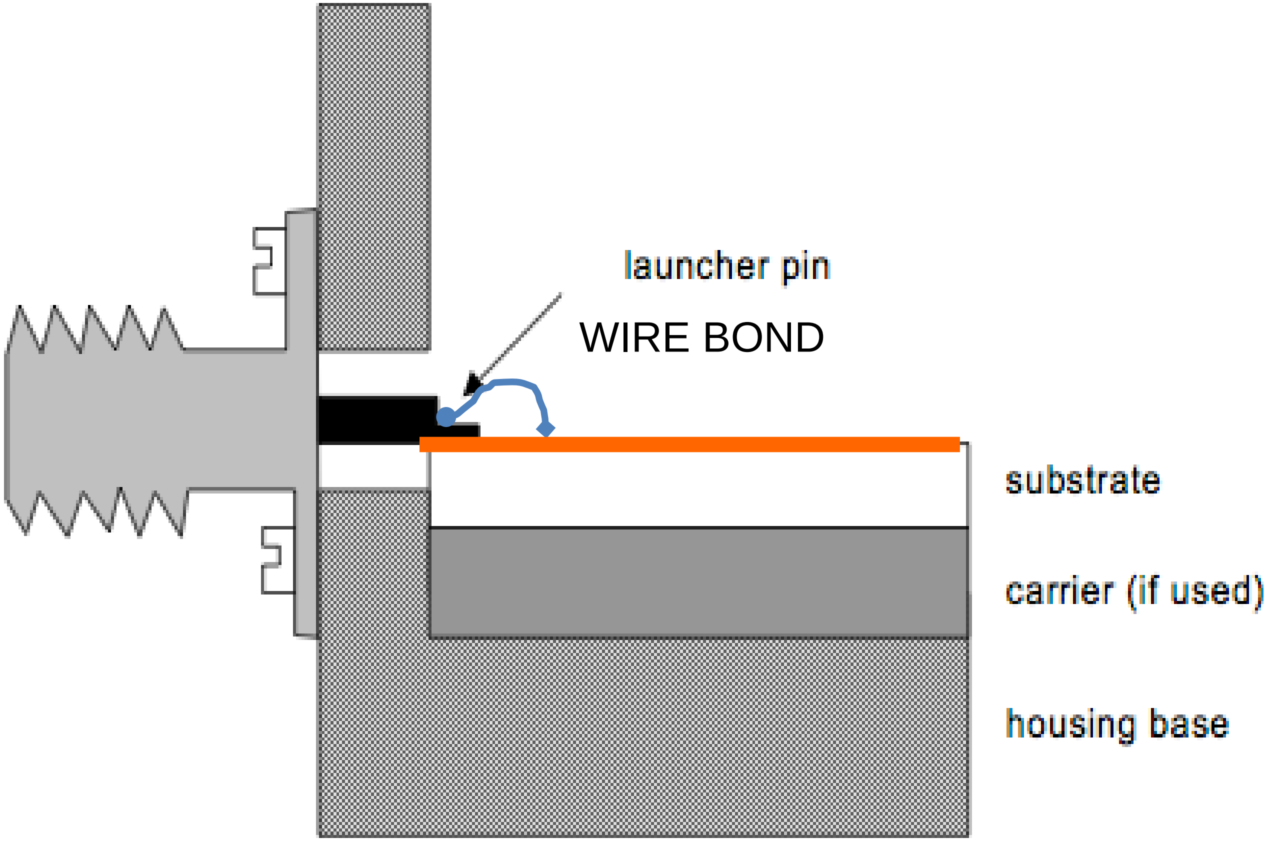
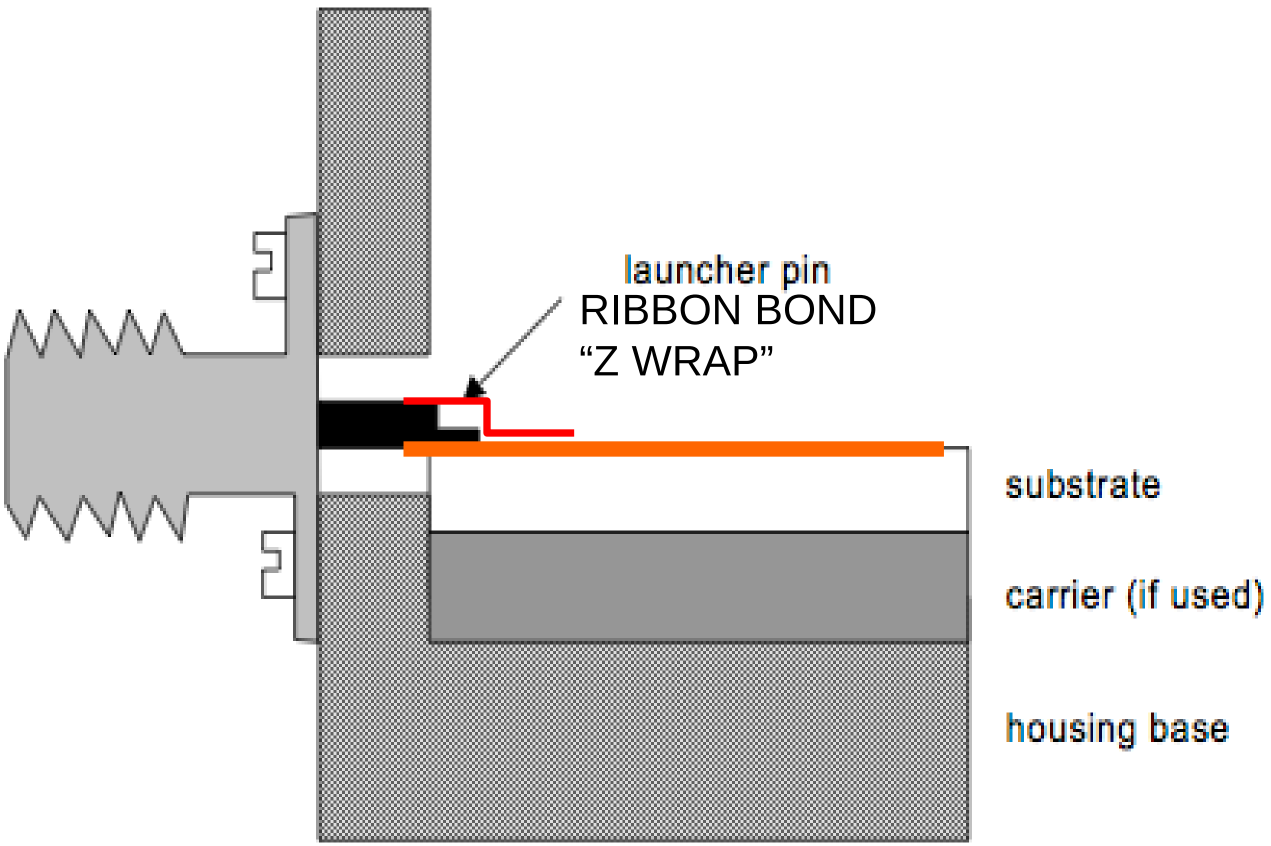


Figure 2.

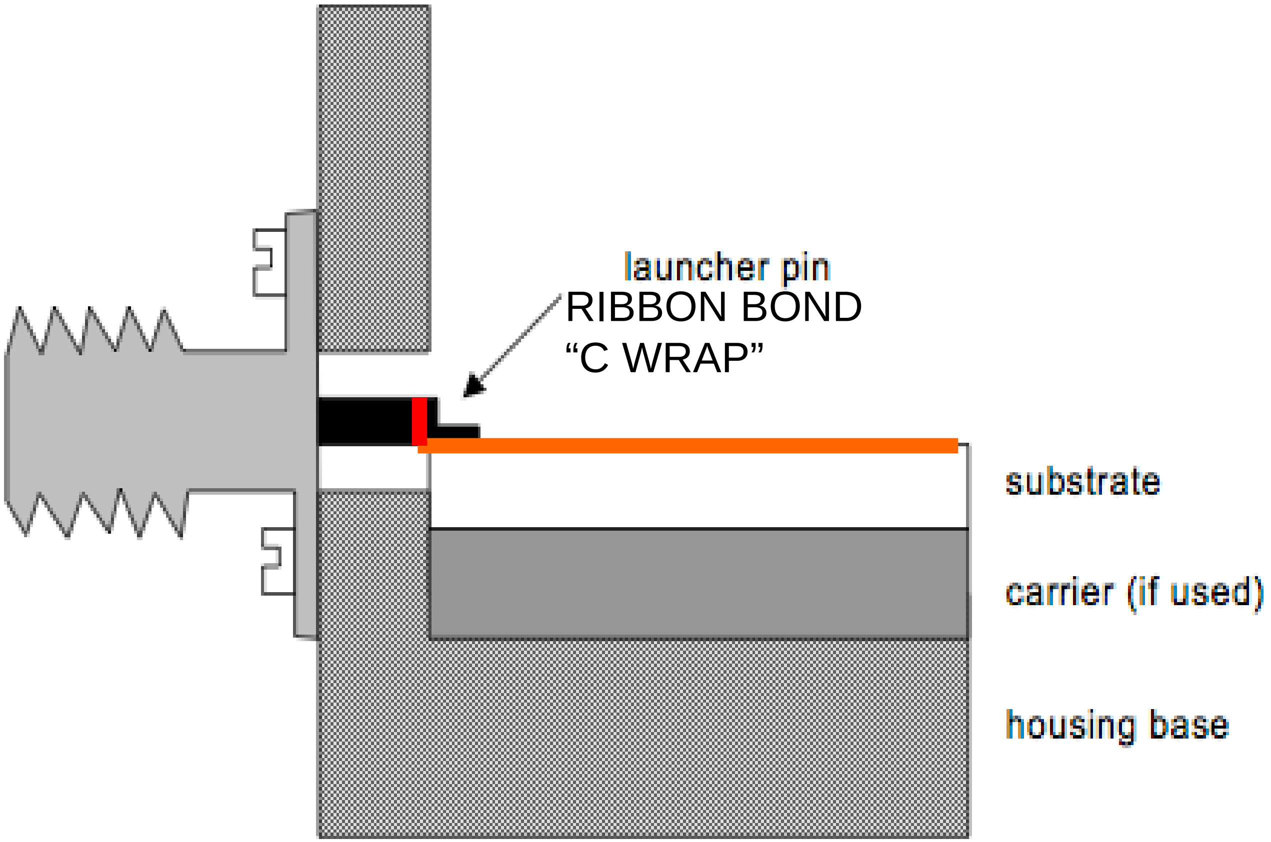
RF Connections-Typical MIC Housing



RF Connections-Typical MIC Housing



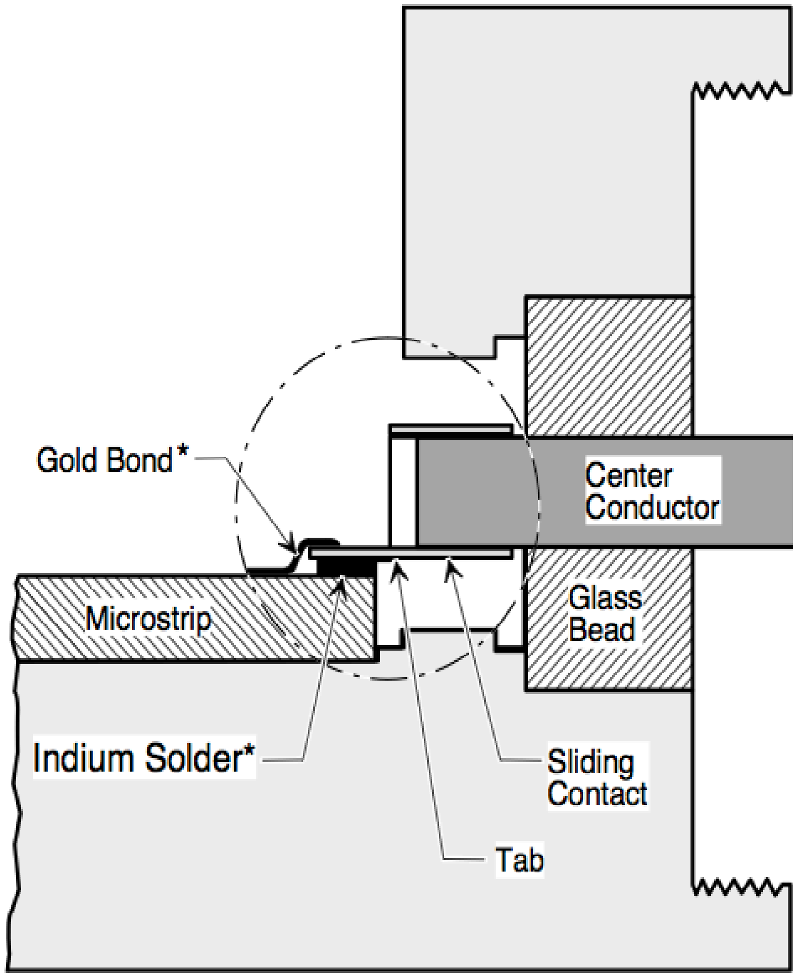
RF Connections-Typical MIC Housing

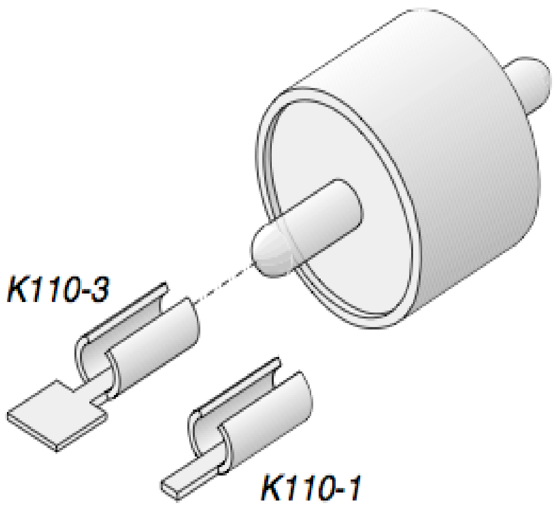


SIDE VIEW

SINGLE OR DOUBLE WRAP

RF Connections





Glass Bead, K110-1, Sliding Contacts for Alumina Microstrip, and K110-3 Sliding Contacts for Duroid Microstrip

Sliding Contacts Installation

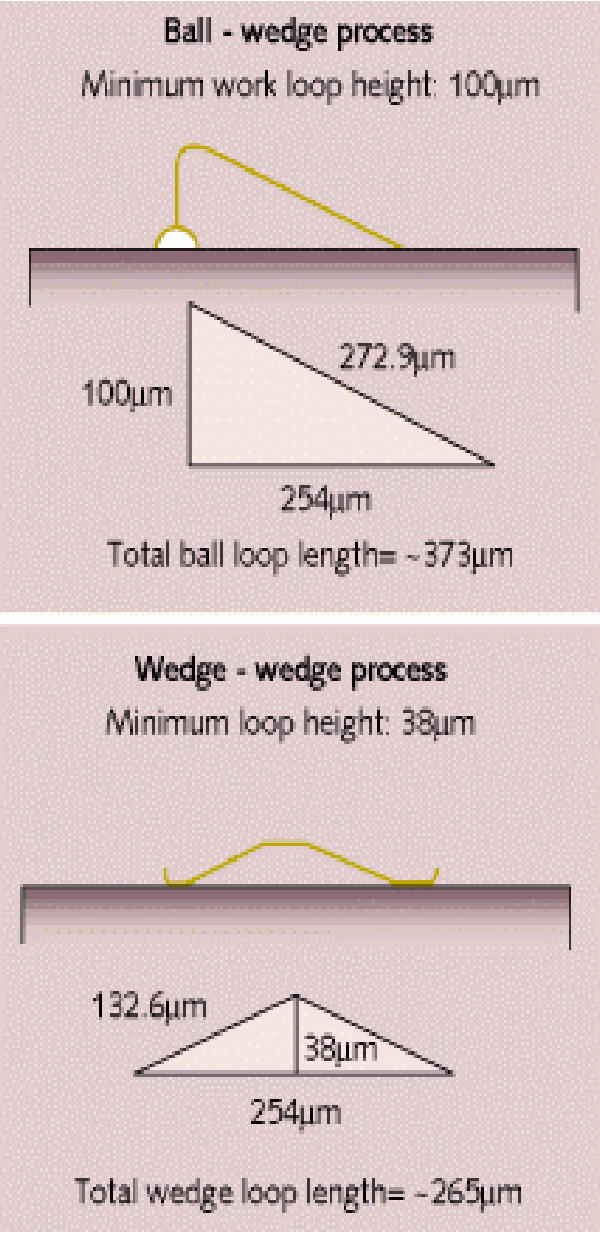
ASSEMBLY-WIRE BOND

Gold Wire Bond vs. Gold Ribbon Bond

Parameter	Wire Bond[1]	Ribbon Bond
Typical Size	0.001 " dia. Wire	.001" x .003" Ribbon
No. of Bonds (using Auto Bonder)	13,000 per Hour	4,000 per Hour
Bond Direction	360 Degrees	Diagonal Only
Pad Impact	Less	More
Average Stage Temp	150 Degrees C.	130 Degrees C.
Lowest Loop	0.006"	0.003"
Average Loop	0.012"	0.006"

Source: Natel (NEO) Design guide
1- Gold wire Ball Bonding

ASSEMBLY-WIRE BOND



29% decrease in length and inductance with a 100µ (4 mil loop)

Source:Natel (NEO) Design guide

WIRE BOND INDUCTANCE

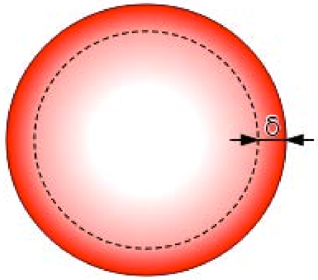
$$L_{\text{bond-wire}} = 2 \times 10^{-4} \ell \left(\ln \frac{4\ell}{d} + 0.5 \frac{d}{\ell} - 1 + \frac{\delta}{d} \right)$$

where δ is skin depth

SKIN DEPTH

AC current density $J = J_S\, e^{-d/\delta}$

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}}$$



where

ρ = resistivity of the conductor

ω = angular frequency of current = 2π × frequency

μ = absolute magnetic permeability of the conductor[1]

d= distance from the surface

Skin Depth	J	Total Current between surface and skin depth
1	36.8%	63.2%
2	13.5%	86.5%
3	5.0%	95.0%
4	1.8%	98.2%
5	0.7%	99.3%

MICROWAVES 101

Rule of thumb: always plan on providing at least five skin depths of low-loss conductor This will keep more than 99% of your electrons happy and provide good performance without wasting precious metals.

Rule of thumb: when using copper-clad boards, you usually won't have to give skin depth another thought, because you will have at least 700 microinches of copper (1/2 ounce) on both sides, which is five skin depths down to 330 MHz.

AT 10 GHZ

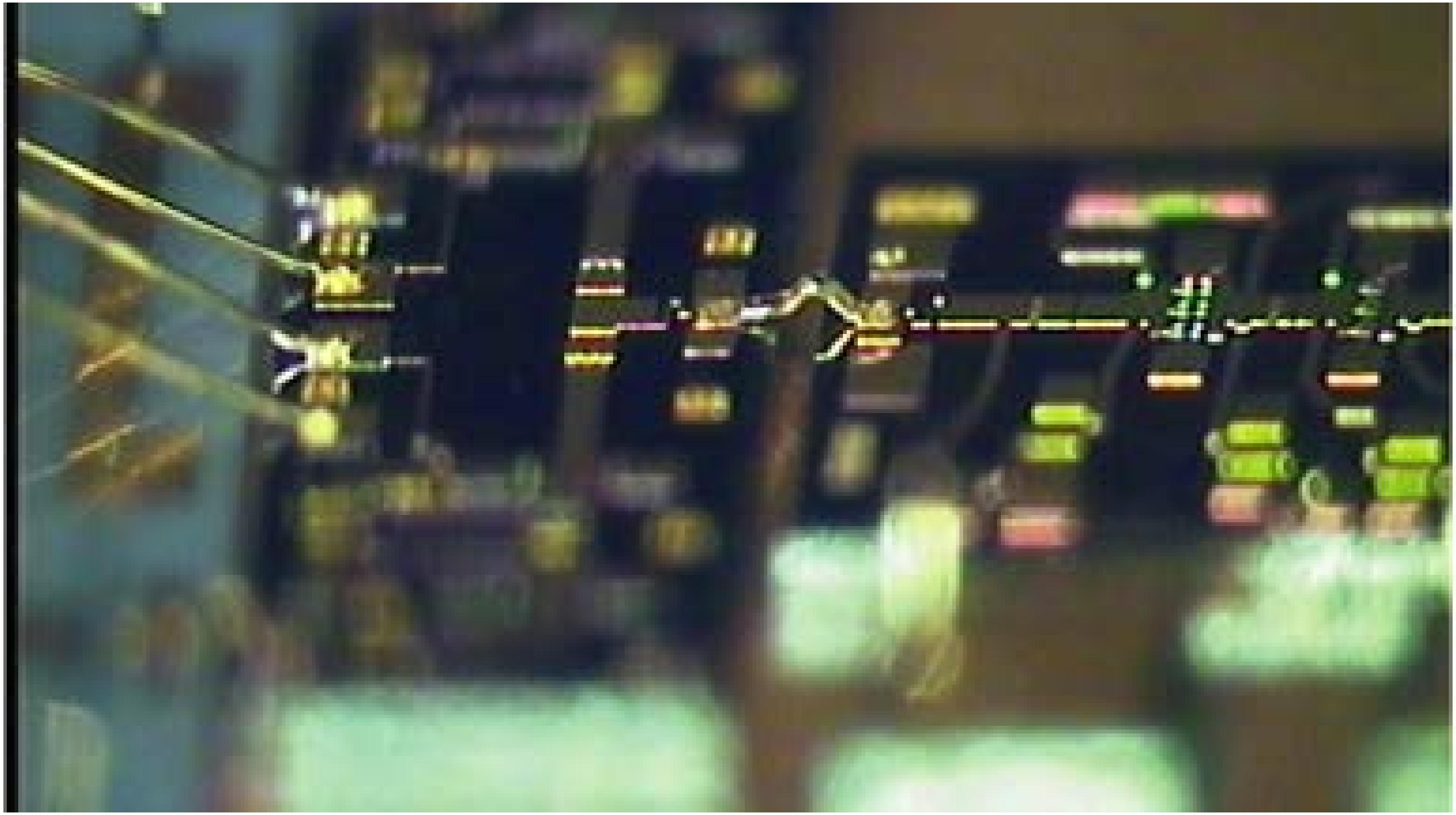
Conductor	Skin depth (μm)
Aluminum	0.80
Copper	0.65
Gold	0.79
Silver	0.64

ASSEMBLY-WIRE BOND

MEASURED INDUCTANCE, INSERTION LOSS AND F_{SR} FOR DIFFERENT WIRES					
	Single 0.8 mil round wire	*Double 0.8 mil round wire (S=10 mils)*	*Double 0.8 mil round wire (S=5 mils)*	*Single 2 mils round wire*	*0.5 × 2 mils ribbon wire*
Inductance @ 10 GHz (nH)	4.238	2.509	2.769	2.98	3.077
Insertion loss @ 10 GHz (dB)	3.24	2.06	2.29	2.47	2.5
Self-resonant frequency (GHz)	15.3	13.4	14.6	14.82	14.8

Natel (NEO) Design guide

Die to Die Interconnect



RF Connections Standoff Stitch or Ball Stitch ball (BSB)

1-Ball on GaAs Die pad

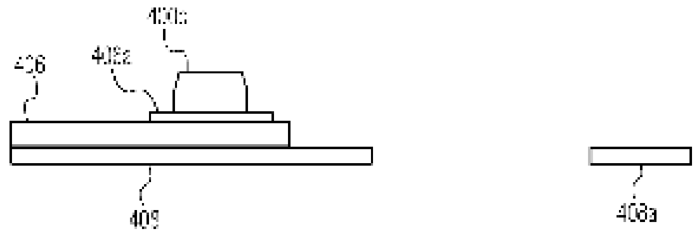


FIG. 3A

2-Ball on Microstrip

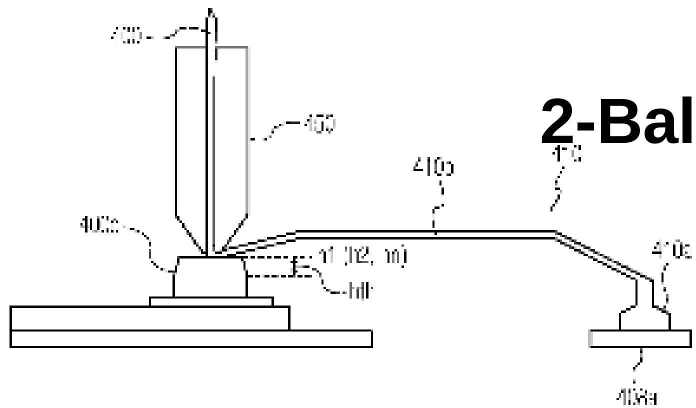
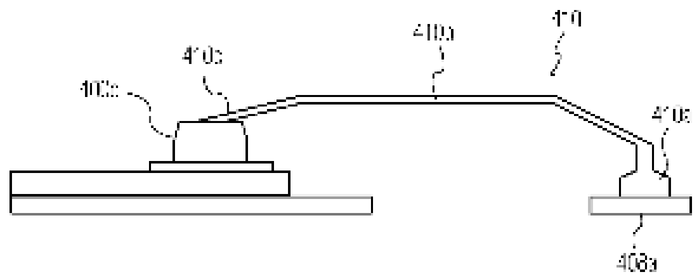


FIG. 3B

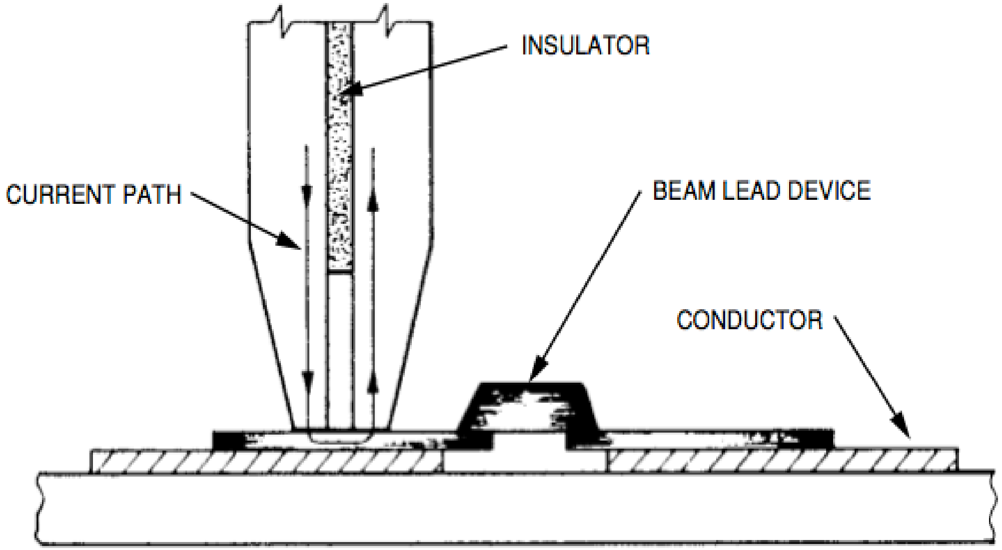
3-Stitch on the Ball on GaAs Die

Source: Wire loops, methods of forming wire loops, and related processes US 20130125390 A1



RF Connections

Parallel Gap - A parallel gap welding system is shown in Figure 1. In this case, the electrodes are bonded together with an insulator between the electrodes. The current is then passed from one electrode to the other through the part to be welded, in this case the beam lead. The energy required to fuse the bottom conductor must be generated at this interface. The spacing between the electrodes should be kept to a minimum (below 0.3 millimeter) to minimize the substrate conductor heat-up and thus prevent the conductor from lifting off the substrate. This is especially important with very thin lines (8 micron copper). The lines should be covered by a gold finish of more than 0.5 micron if possible. One alternative is to use a nickel layer between the copper and the gold.

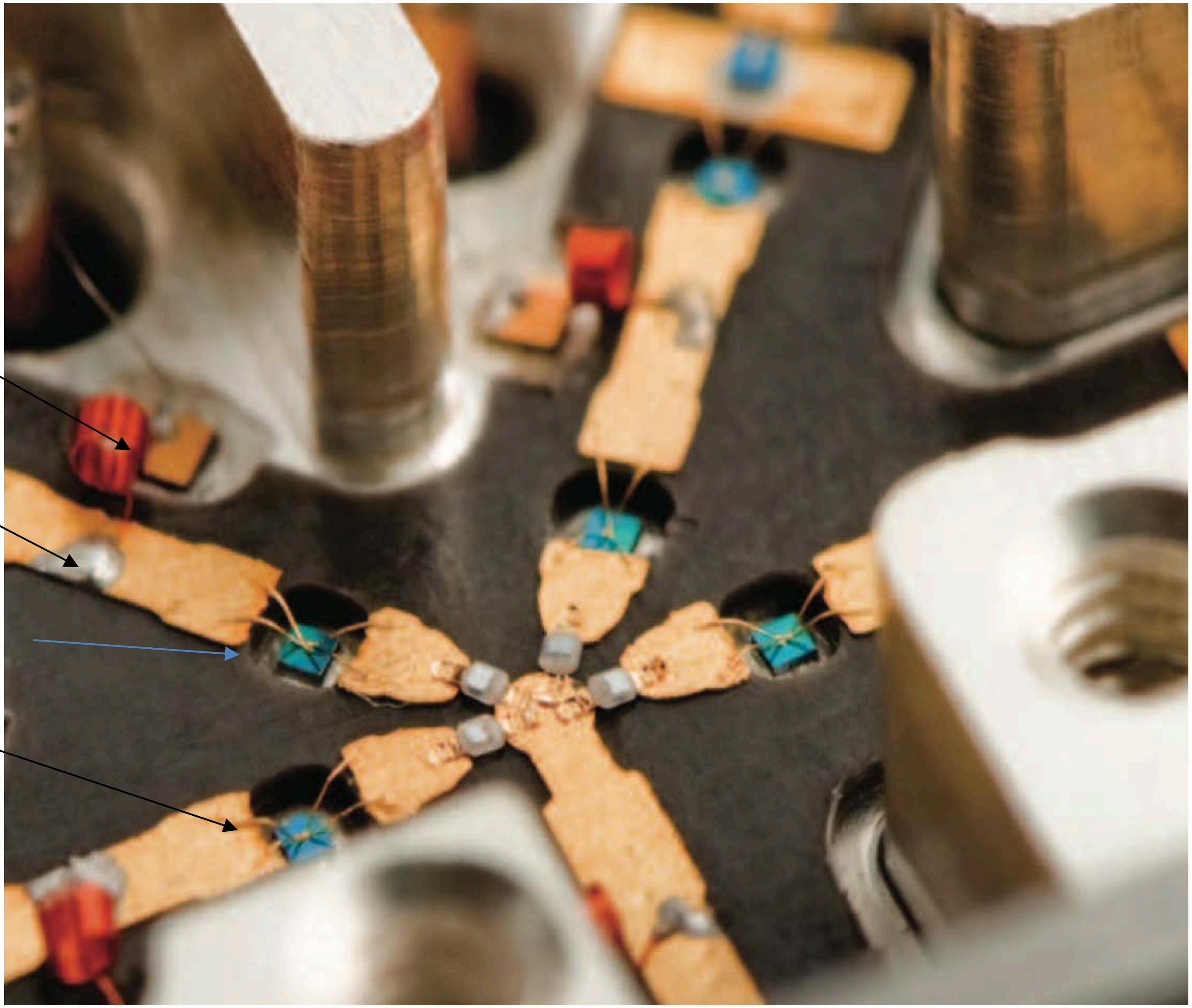


RF Connections

Soldering Air wound coil to Parallel Plate Capacitor and Microstrip

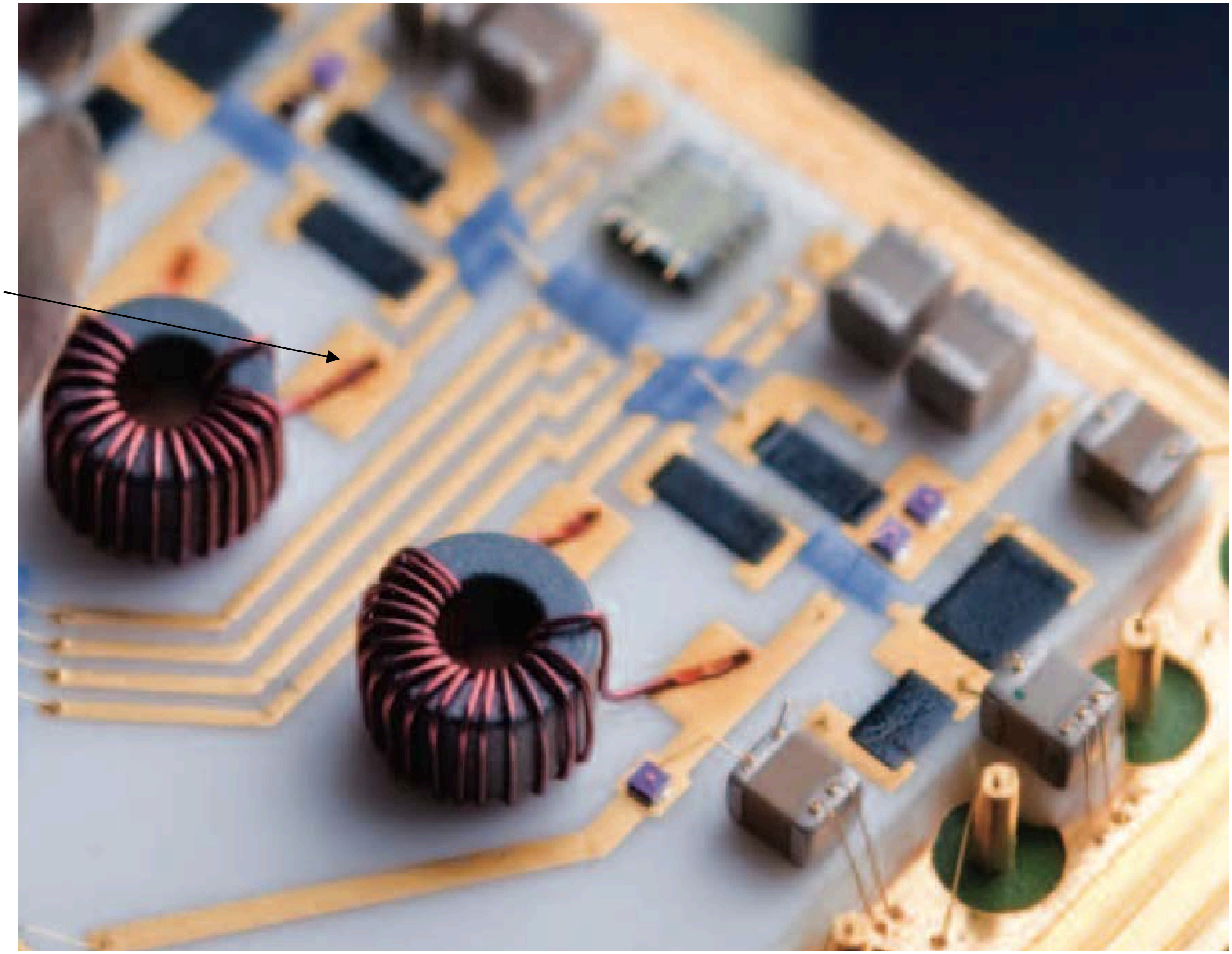
Bonding PIN Diode in a cavity in the duriod Microstrip.

Parallel gap bonding the beam lead diodes



RF Connections

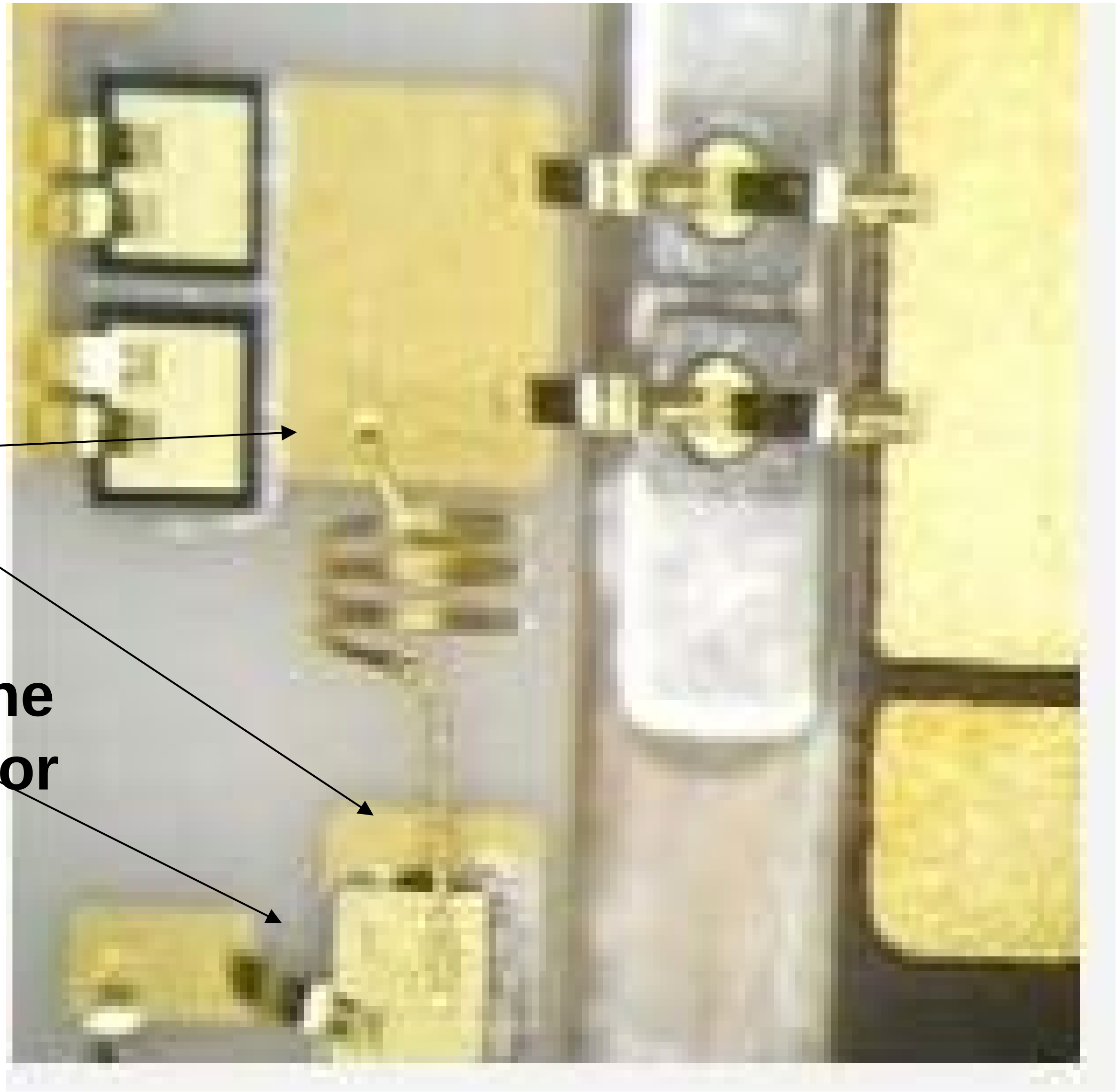
Parallel gap welding to thick film conductor



RF Connections

Gap welding the Air Wound gold wire Coil to the Microstrip And parallel plate capacitor

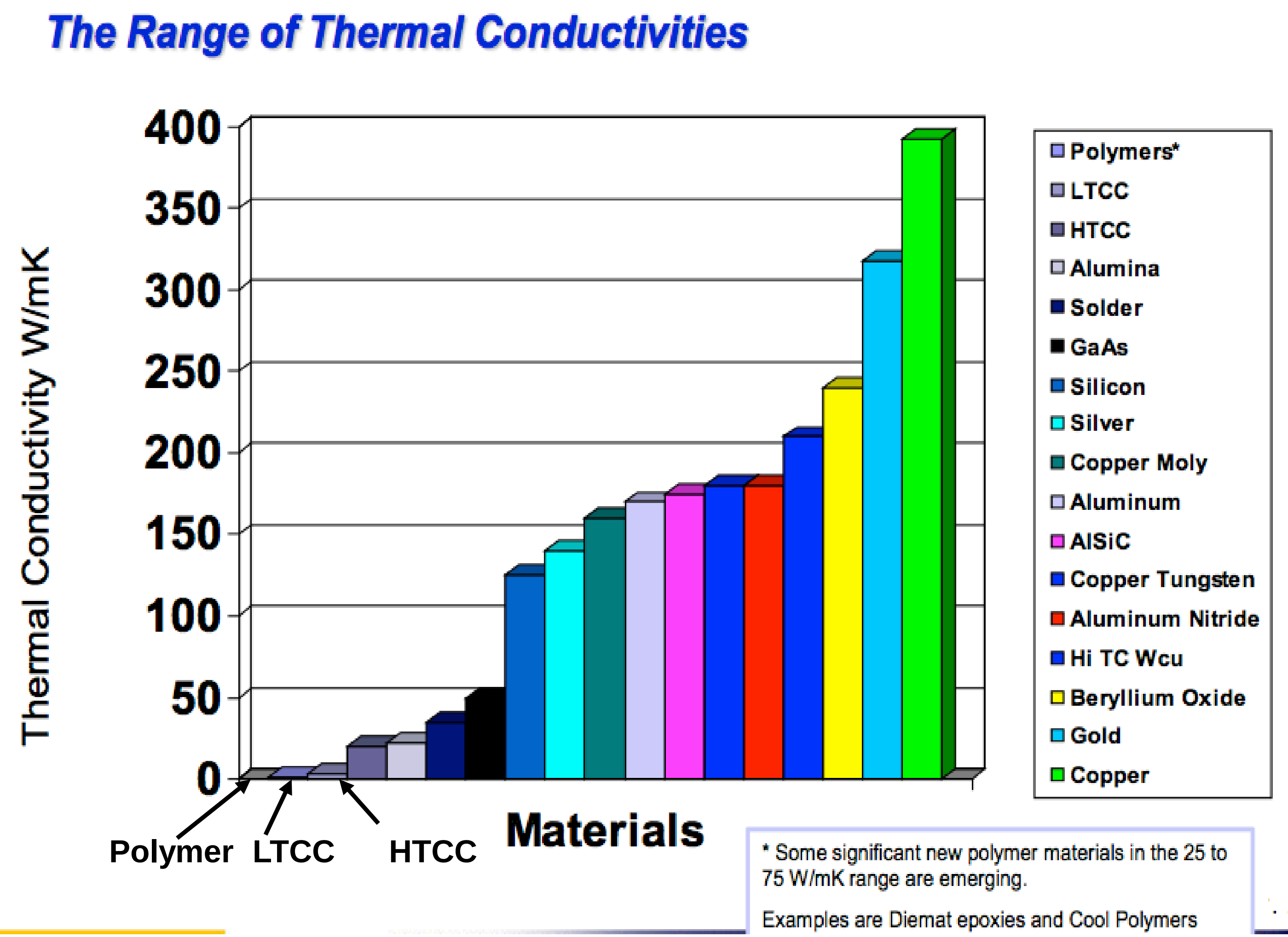
Ribbon Bonding to the parallel plate capacitor



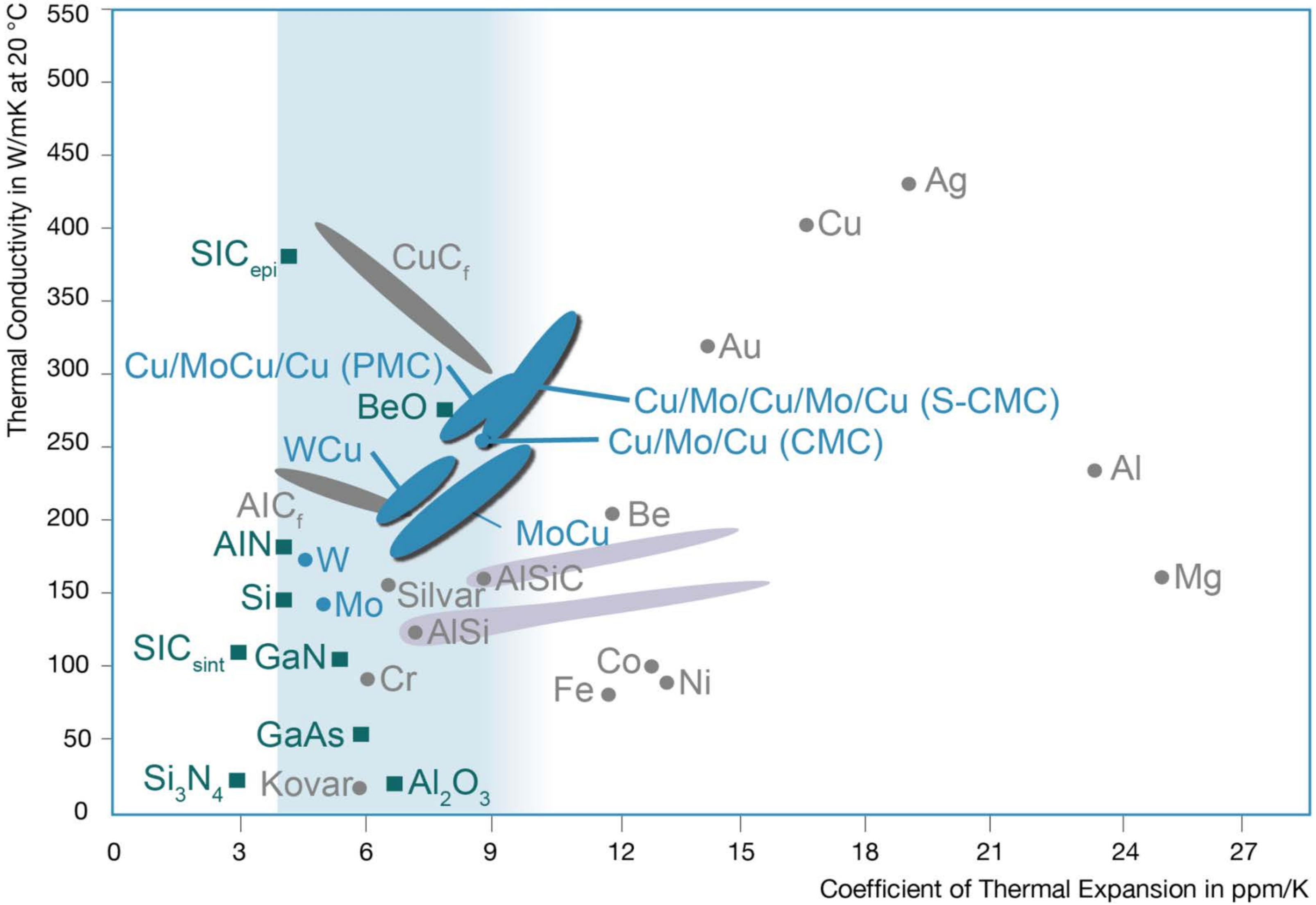
Source: Scott MacKenzie Bonding Sources

MATERIAL THERMAL PROPERTIES

PACKAGE SUBSTRATE MATERIALS

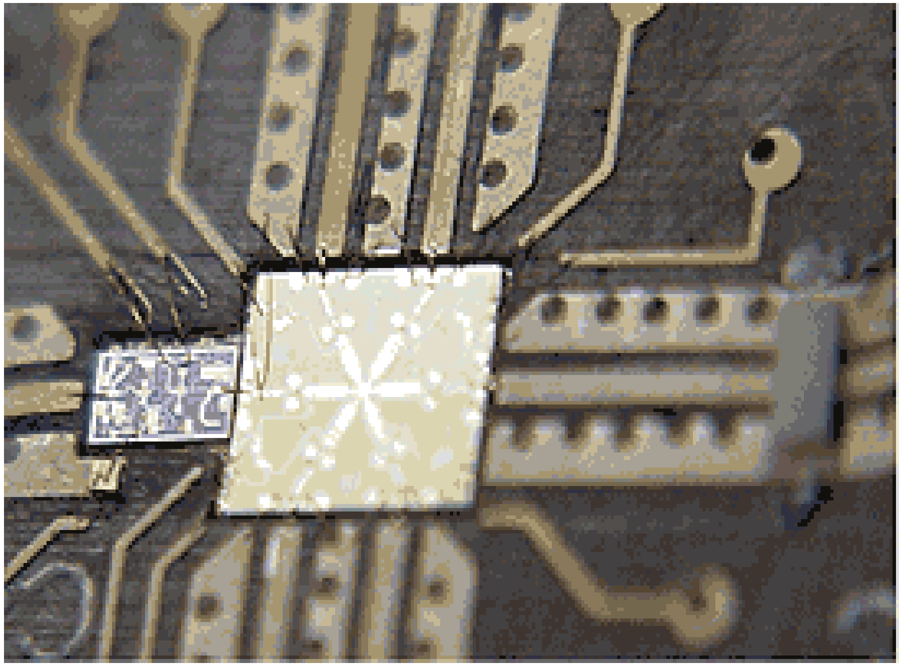


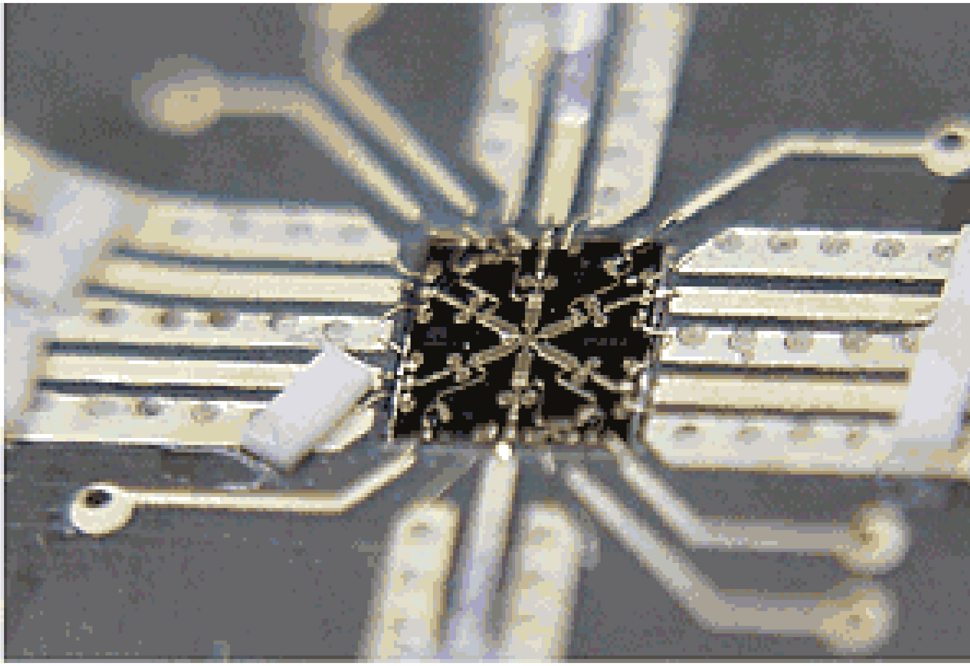
Thermal Conductivity vs CTE



Ref: Plansee

MMIC ASSEMBLY



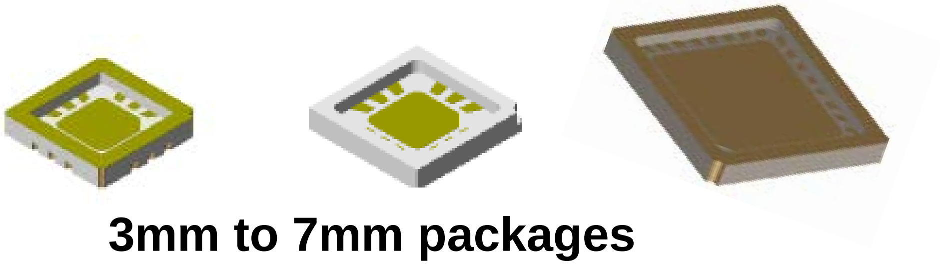


3. This close-up shows the close proximity of the switch and LNA MMICs in the pocket-mount assembly (left). The large chip is the flush-mounted six-way switch (right), which has one shunt PIN diode in each of the six legs of the star. The input port can be any leg and the output can be any other leg. There is no common arm. The pieces of white material are alumina, placed between the microstrip line and ground, and used as a tuning technique.

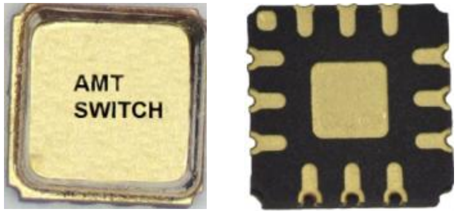
http://mwrf.com/materials/mounting-technique-aids-mmic-performance

SMT and Hermetic SMT Components

- **Ceramic QFN high frequency package**
- **Hermetically sealed**

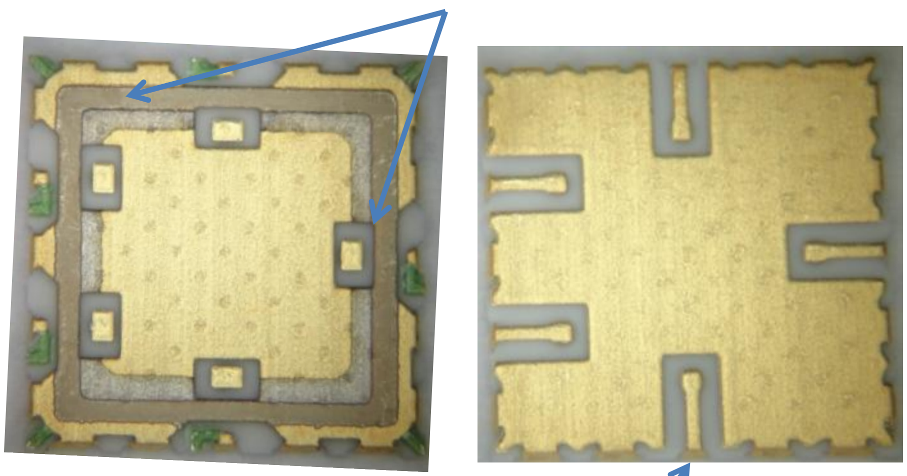


3mm to 7mm packages



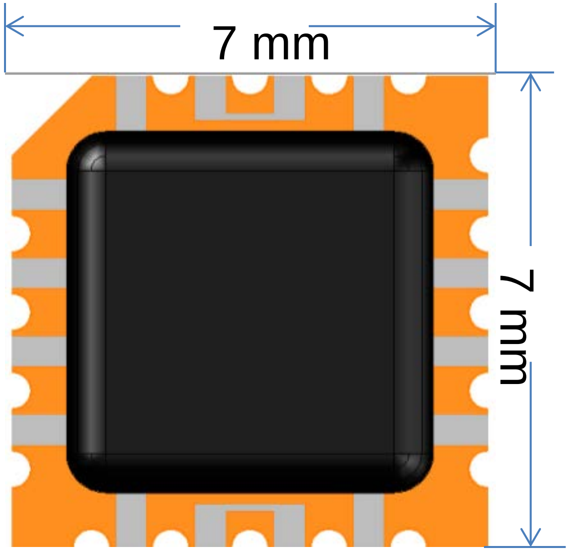
3mm Custom RF SWITCH
Hermetically sealed

Gold Tin for dome cover seal



7mm Thick Film package

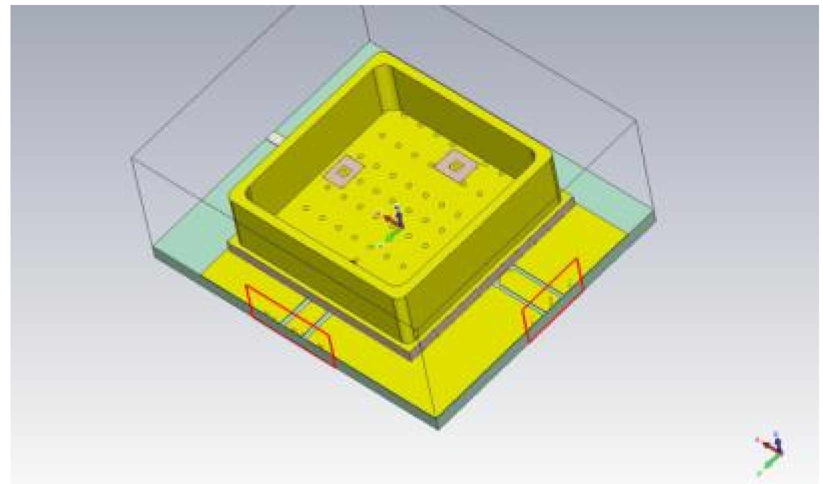
Castellations for solder inspection at next level



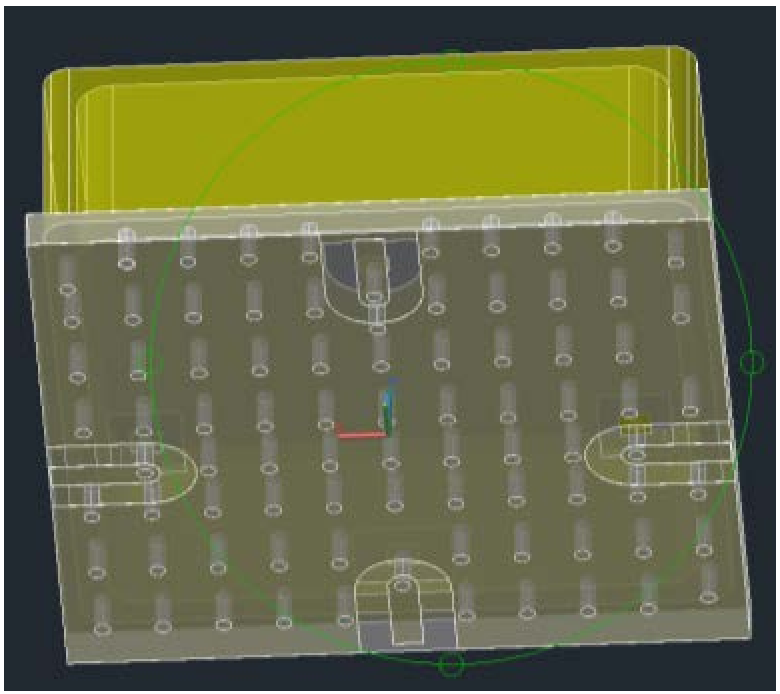
Non-Hermetic Low cost SMT With Glop top

Package design capabilities EM Simulation

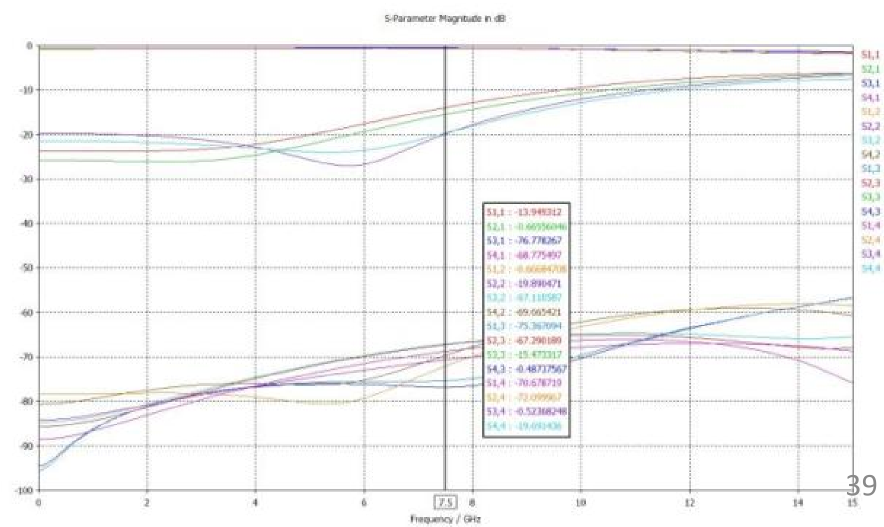
- **Ceramic QFN high frequency package**
- **Hermetically sealed**



Model mounted on a Rogers Board



Model Thick-Film Via transition



MIL-STD-883 2010/2017 VISUAL INSPECTION eBook Review[1]

2. APPARATUS. The apparatus for this test shall include optical equipment capable of the specified magnification and any visual standards (gauges, drawings, photographs, etc.) necessary to perform an effective examination and enable the operator to make objective decisions as to the acceptability of the device being examined. Adequate fixturing shall be provided for handling devices during examination to promote efficient operation without inflicting damage to the units.

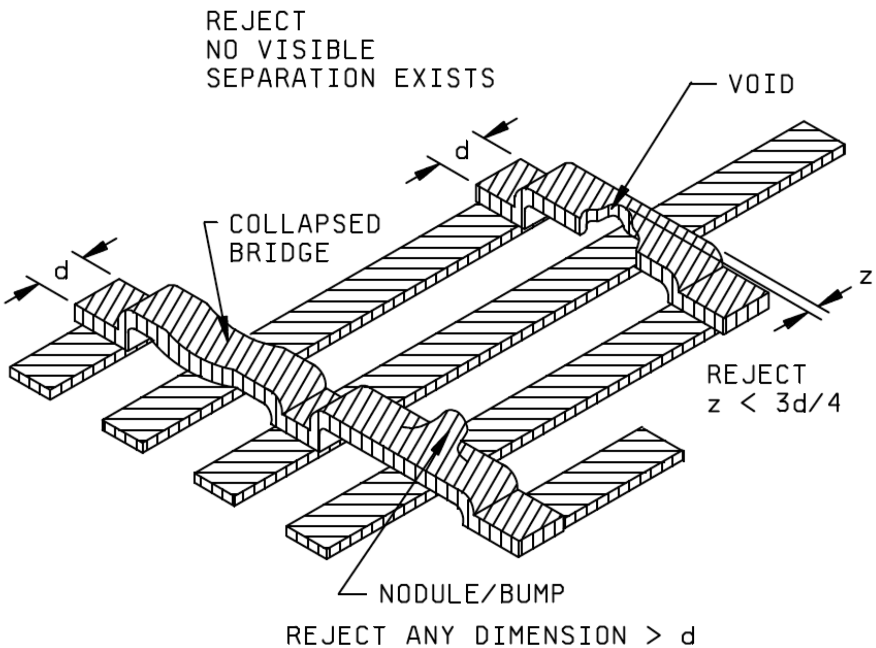
2.1 GaAs device requirements. GaAs devices shall be inspected to all applicable criteria as listed herein. GaAs microwave devices shall also have additional specific criteria as listed and the applicable high power magnification for individual features of GaAs microwave devices shall be selected from the following table.

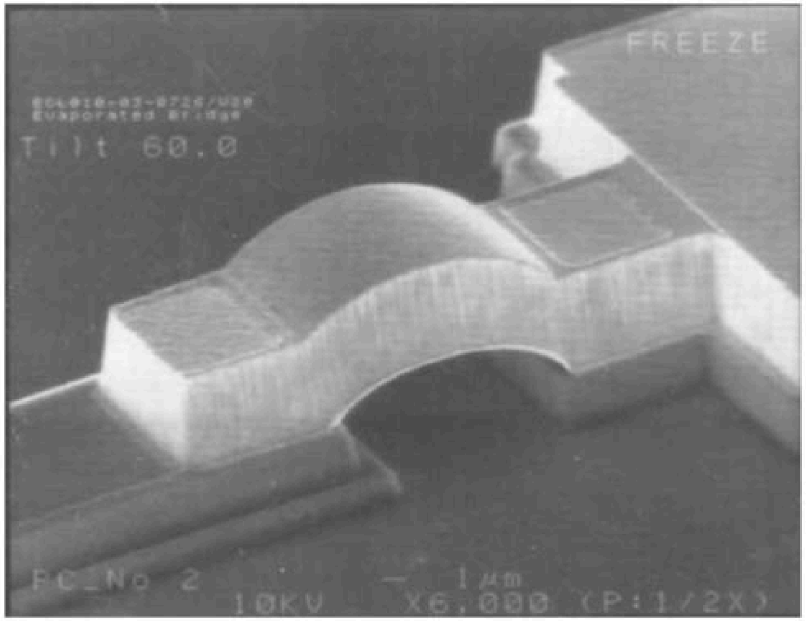
TABLE I. GaAs microwave device high magnification requirements.

Feature Dimensions	Magnification range
> 5 microns	75 - 150x
1 - 5 microns	150 - 400x
< 1 micron	400 - 1000x

MIL-STD-883 2010/2017 VISUAL INSPECTION eBook Review

MIL-STD-883K
w/CHANGE 2





SUMMARY OF CHALLENGES

- Electrical
- Mechanical
- Assembly
- Components
- Packages
- Reliability
- Performance
- Cost

Beware—the Microwave May be Listening!

http://www.mwrf.com/blog/beware-microwave-may-be-listening