Alcatel Alenia Space

3rd CTB WG Hybrids Technical Presentations Day

*ESTEC - Noordwijk - May 3rd, 2006*

# Microwave organic PCBs for space applications

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- organic versus non-organic
- materials and manufacturers: substrates, prepregs, resistors
- more on materials
- existing solutions for RF multilayer boards
- electrical results on RO4003 multilayers boards
- qualification of RF boards for FaFr antenna
- RF Printed Circuit Board: not so new
- questions and discussion

# materials for RF substrates



## inorganic substrates

- monocristal : quartz, sapphire
- ceramic : aluminum oxide ($Al_2O_3$)
  aluminum nitride (AlN)
- titanates : Mg, Ca, Zr, Sn, Ba…
- and, why not : diamond

## organic substrates

- thermoplastic : Teflon® based
- thermoset : polyimide
  quartz-polyimide
  ceramic thermoset polymer composite

# why organic materials ?



- weight reduction
  - ✓ lower density
  - ✓ CTE compliant with light materials
    → less mechanical parts for the assembly
- cost reduction
  - ✓ cheaper material
  - ✓ manufactured as printed circuit board
  - ✓ easier to machine with specific shapes
  - ✓ less brittle
- better electrical performances
  - ✓ larger substrates → less interconnections
  - ✓ dielectric constant from 2.2

# organic versus non-organic



| Material | εr | Tan δ $10^{-4}$ | TCE ppm/°C | TC $W.m^{-1}.K^{-1}$ |
|---|---|---|---|---|
| Quartz-$SiO_2$ | 3.75 | 1.5 | 0.5 | 1.5 |
| Cordierite | 4.9 | 10 | 3.5 | 3 |
| Steatite | 6-6.5 | 6 | 7-9 | 2-4 |
| Forsierite | 6-8 | 2-3 | 8.5-10 | 3 |
| BeO | 6.6 | 2 | 7.5 | 260 |
| AlN | 8.5 | 3-10 | 4.5-5 | 107 |
| $Al_2O_3$ 99.6% | 9.2 | 2 | 7.2 | 33 |
| $Al_2O_3$ 96% | 10.2 | 2 | 7.5 | 21 |
| Mg, Za titanate | 20 | 1.5 | 8 | 7 |
| Zr, Sn titanate | 35 | 1.5 | 7.4 | 2 |
| Ba, Nd titanate | 85 | 3 | 8 | 2 |

| Material | εr | Tan δ $10^{-4}$ | TG °C |
|---|---|---|---|
| Standard FR4 | 4.5 | 260 | 125 |
| FR4 / BT | 4 | 150 | 185 |
| Cyanate Ester | 3.8 | 90 | 240 |
| Modif. polyimide | 4 | 150 | 220 |
| Quartz polyimide | 3.5 | 50 | 260 |
| Pure PTFE | 2.05 | 4 | 327 |
| PTFE based | 2.2-10 | 10-35 | >250 |
| Thermoset | 3.2-10 | 15-40 | >280 |

# key points for RF organic PCB



- electrical performances
  - ✓ diel. cte and losses
    - different figures as a function of measurement method
    - to be checked for the real application
- temperature stability
  - ✓ diel. cte versus temperature: variation and linearity
- frequency stability
- coefficient of thermal expansion
  - ✓ range of temperature to be specified
  - ✓ linked to plated through-hole reliability

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# materials and manufacturers: substrates



- PTFE based + woven glass or glass fibers (ex.: RT5880)
  - ✓ diel. cte: 2.1 to 3.2 as a function of the ratio PTFE / glass
  - ✓ high TC($\varepsilon_r$)
  - ✓ very low losses (0.001 to 0.003)
  - ✓ stabilized TCE in z axis because of woven glasses
- PTFE based + ceramic fillers (ex.: RT6002)
  - ✓ diel. cte: 2.9 to 10.2 with low TC($\varepsilon_r$)
  - ✓ low losses (0.0012 to 0.004)
  - ✓ low TCE(z) but poor stability in x,y
- hydrocarbon matrixes (ex.: TMM & RO4000 series)
  - ✓ rigid materials, high Tg, without PTFE
  - ✓ compatible with FR4 processes
  - ✓ diel. cte: 3 to 10 with low TC($\varepsilon_r$) and losses $\geq$ 0.002

# materials and manufacturers: prepregs



## thermoplastics

- ✓ fluoropolymer (as FEP from Dupont), chlorofluoropolymer (as CTFE/6700…)
- ✓ compatible with PTFE substrates
- ✓ low diel. cte and losses
- ✓ high temperature process (>200°C)

## FR4 prepreg

- ✓ lower temperature process (>200°C)
- ✓ poor dielectric properties: diel. cte and losses

| | FEP | CTFE | FR4 | Speedboard |
|---|---|---|---|---|
| Dielectric Constant | 2.1 | 2.3 | 4.5 | **2.6** |
| Loss Tangent | 0.001 | 0.003 | 0.018 | **0.004** |
| Lamination Temperature, °C | 280 | 220 | 175 | **220** |
| Lamination Time, hrs. | 0.5 | 0.5 | 1 | **2** |

# materials and manufacturers: prepregs



## hydrocarbon matrixes based

- ✓ new offer compatible with hydrocarbon matrixes substrates
  → homogeneous multilayers
- ✓ high Tg thermoset (>250°C)
- ✓ bonding temperature ≈ 175°C
  → i.e. lower then Tg : easier to manufacture sequential boards
- ✓ good compromise between process capabilities / electrical performances

# materials and manufacturers: resistors



## 4 processes identified

- ✓ thin film resistor layer on copper:
  *Ohmega-Ply, Gould, Shipley*
- ✓ screen printed pastes:
  *Inboard, Asahi, Electra*
  *and Dupont*
- ✓ chemical additive deposition:
  *MacDermid*
- ✓ resistor chips

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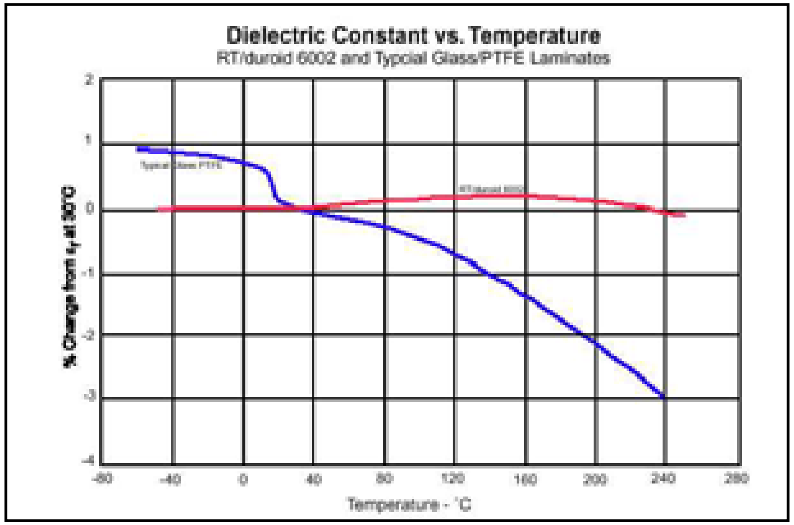
# more on materials: substrates



## from Rogers

- ✓ PTFE based with ceramic fillers
  - duroid RT6002 as the reference for electrical properties
    quite no variation of diel. cte in temperature
    very low CTE on Z axis
  - RO 3003 as the "low cost" version of RT6000 serie
    as an associated prepreg (3001) with $T_{PRESS}$ = 220°C
    seems difficult to process

| | RO3003 | RT 6002 |
|---|---|---|
| $\varepsilon_r$ (@ 10 GHz) | 3.00 ±0.04 | 2.94 ±0.04 |
| **Tan** $\delta$ (@ 10 GHz) | 0.0013 | 0.0012 |
| **TC($\varepsilon_r$),** ppm/°C | +13 | +12 |
| **CTE**, ppm/°C X, Y, Z | 17, 17, 24 | 16, 16, 24 |
| Abs. $H_2O$ % | <0.1 | 0.1 |
| UL 94V0 | Yes | Yes |

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## from Rogers

- ✓ thermoset (without PTFE)
  - TMM: on the market since beginning 90s
    breakable and not available in thin layer
  - RO 4000 series
    high Tg : 280°C
    available prepregs: RO4403 or RO4450 : $T_{press}$ = 170°C

- ✓ PTFE versus non PTFE

| | 4003 | RT 6002 | 4403 | 4450 | Speedboard |
|---|---|---|---|---|---|
| $\varepsilon_r$ (@ 10 GHz) | 3.38 ±0.05 | 2.94 ±0.04 | 3.17 ±0.05 | 3.54 ±0.05 | 2.6 |
| **Tan** $\delta$ (@ 10 GHz) | 0.0027 | 0.0012 | 0.005 | 0.004 | 0.004 |
| **TC($\varepsilon_r$),** ppm/°C | +40 | +12 | -- | -- | -- |
| **CTE**, ppm/°C X, Y, Z | 11, 14, 46 | 16, 16, 24 | 16, 19, 80 | 19, 17, 60 | 56 |
| Peel Strength | 5 | 8.9 | NA | NA | NA |
| Abs. $H_2O$ % | 0.04 | 0.1 | 0.05 | 0.05 | 0.02-0.04 |
| UL 94V0 | No | Yes | No | Yes | Yes |

# more on materials: substrates



## from Arlon

- ✓ PTFE based
  - CLTE : PTFE based with ceramic filler and woven glass
    competitor to RT6002
    available with Omega-Ply copper
    associated preg CLTE-P : $T_{PRESS}$ 280°C !
- ✓ thermoset
  - 25N : competitor to RO4003 with same resin and different fillers
    associated preg with $T_{PRESS}$ @ 170°C

| | CLTE | RT 6002 | 25N | 4003 |
|---|---|---|---|---|
| $\varepsilon_r$ (@ 10 GHz) | 2.94 | 2.94 ±0.04 | 3.38 ±0.06 | 3.38 ±0.05 |
| **Tan** δ (@ 10 GHz) | 0.0025 | 0.0012 | 0.0025 | 0.0027 |
| **TC($\varepsilon_r$),** ppm/°C | -- | +12 | -87 | +40 |
| **CTE**, ppm/°C X, Y, Z | 10, 12, 35 | 16, 16, 24 | 15, 15, 52 | 11, 14, 46 |
| Abs. $H_2O$ % | 0.04 | 0.1 | 0.09 | 0.04 |
| UL 94V0 | Yes | Yes | No | No |

## from Neltec

- ✓ series N9000 for high frequency application
  - PTFE + woven glass + ceramic fillers to adjust the diel. cte around 3
  - high TCE in z > 70 ppm/°C
- ✓ new material: N9000-13 RF with PTFE and epoxy
  - $\varepsilon_r$ =3, tan $\delta$ = 0.004 @10GHz, CTE = 67 ppm/°C in Z
  - manufacturing process as for PTFE

| | | 9294 | 9300 | 9320 | 9338 | 9348 | 9350 |
|---|---|---|---|---|---|---|---|
| Typical Parameter | Test Method | NH SERIES | | | | | |
| Dielectric Constant at 10 GHz (Dk) | IPC-TM-650, 2.5.5.5 | 2.94±.07 | 3.00±.07 | 3.20±.07 | 3.38±.10 | 3.48±.10 | 3.50±.10 |
| Dissipation Factor at 10 GHz (Df) | IPC-TM-650, 2.5.5.5 | 0.0022 | 0.0023 | 0.0024 | 0.0025 | 0.0030 | 0.0030 |
| Thermal Conductivity | ASTM F-1225 | 0.230 W/m/K | | | | | |
| Coefficient of Thermal Expansion (CTE) | IPC-TM-650, 2.4.41 | | | | | | |
| X | | 9 ppm/°C | | | | | |
| Y | | 12 ppm/°C | | | | | |
| Z | | 71 ppm/°C | | | | | |
| Flammability | IPC-TM-650, 2.3.10 | V-0 | | | | | |

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# more on materials: substrates



- from Taconic
  - ✓ less RF products available in Europe
  - ✓ only based on PTFE with very high CTE in X axis

| | TLY (also: 605) | TLX / TLT (also: 601, 602) | TLE-95 | TLC | RF-30 | RF-35 / RF-35P | RF-60 | CER-10 |
|---|---|---|---|---|---|---|---|---|
| DK @ 10 GHz | 2.17-2.33 (+/- 0.02) | 2.40-2.60 (+/- 0.04) | 2.95 (+/- 0.05) | 2.70, 3.00, 3.20 (+/- 0.05) | 3.0 (+/- 0.1) | 3.50 (+/- 0.1) | 6.15 (+/- 0.25) | 10.0 (+/- 0.5) |
| Df @ 10 GHz | 0.0009 | 0.0019 (TLT: 0.006 @ 1 MHz) | 0.0028 | 0.0029 | 0.0014 (@ 1.9 GHz) | 0.0025 (0.0018 @ 1.9 GHz) (RF-35P: 0.0033 @ 10 GHz) | 0.0028 | 0.0035 |
| Peel Strength (1 oz ED copper) | 12 lbs/in | 12 lbs/in | 12 lbs/in | 12 lbs/in | 10-12 lbs/in | 10 lbs/in | 8 lbs/in | 8 lbs/in |
| Moisture Absorption | < 0.02 % | < 0.02 % | < 0.02 % | < 0.02 % | < 0.02 % | < 0.02 % | < 0.02 % | 0.02 % |
| CTE in Z axis (linear to ~ 350 °C) | 280 ppm/°C | 130-145 ppm/°C | 70 ppm/°C | 70 ppm/°C | 125 ppm/°C | 64 ppm/°C (RF-35P: 110) | 75 ppm/°C | 46 ppm/°C |
| CTE in X/Y axis | 20 ppm / °C | 9-12 ppm/°C | 9-12 ppm/°C | 9-12 ppm/°C | 11-21 ppm/°C | 19-24 ppm/°C | 11-13 ppm/°C | 13-15 ppm/°C |
| UL Rating TIR | V-0 105°C | V-0 105 | V-0 105 | V-0 105 | V-0 | V-0 105 | V-0 | V-0 |





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- from Gore
  - ✓ speedboard
    - expensed PTFE with cyanate ester resin
    - thickness after pressing : 2 mils (50 µm)
    - $T_{PRESS}$ : 180 – 220°C
    - but not as good as RT6002 for RF performances

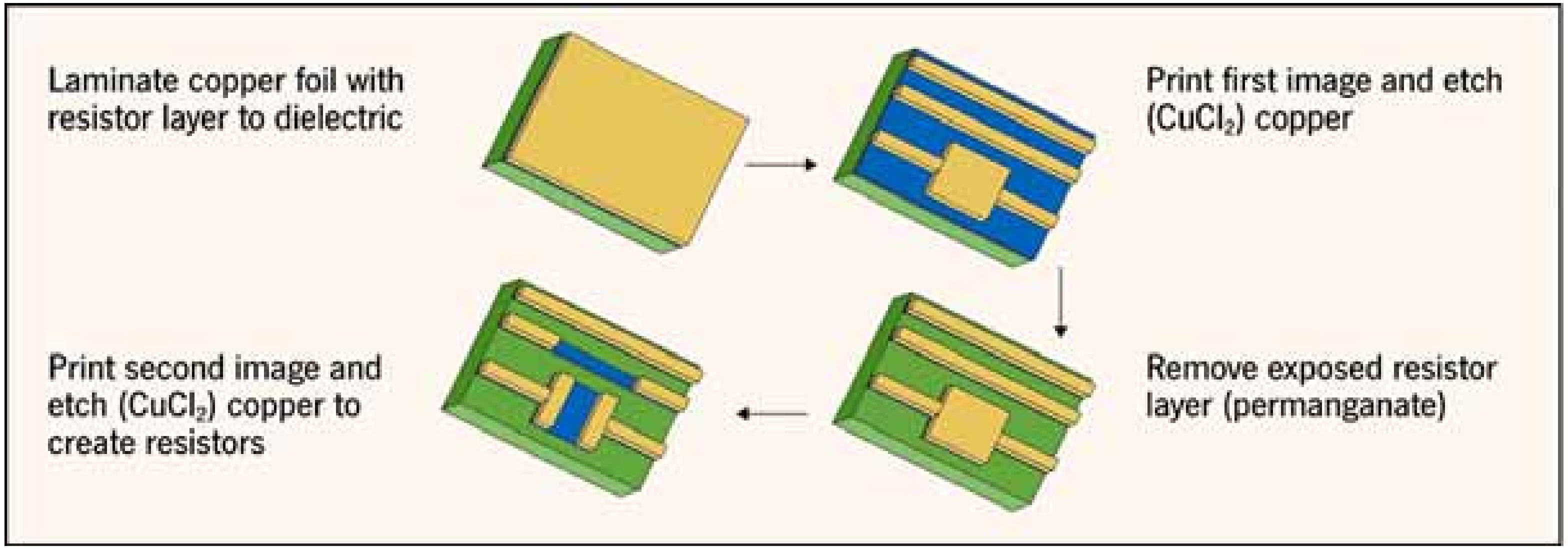
| | **Speedboard** |
|---|---|
| $\varepsilon_r$ (@ 10 GHz) | 2.6 |
| **Tan** δ (@ 10 GHz) | 0.004 |
| **CTE**, ppm/°C X, Y, Z | 56 |
| **Tg** (°C) | 220 |
| Abs. $H_2O$ % | 0.02-0.04 |
| UL 94V0 | Yes |

- from other source : available with the substrate

# more on materials: resistors



- thin film resistor layer on copper:
  *Ohmega-Ply (electrodeposed NiP), Gould (NiCr or NiCrAlSi), Shipley (CVD doped Pt with high resistivity – about 1000 Ω/sq)*
  - ✓ could be laminated onto the substrate
  - ✓ subtractive process with 2 to 3 steps
  - ✓ accuracy ±5 to 10% at least





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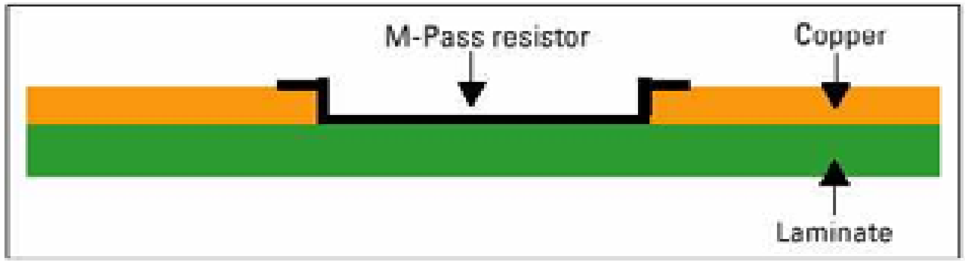
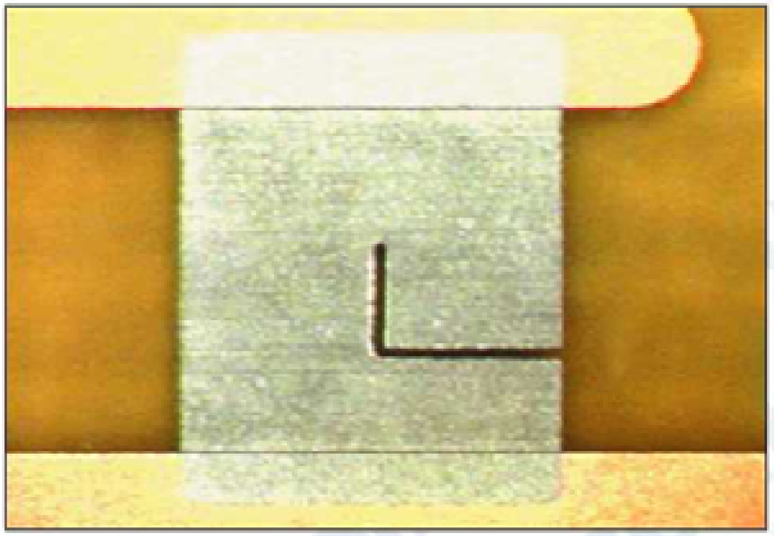
# more on materials: resistors



- screen printed pastes:
  SIMOV-*Inboard (carbon paste 18Ω, 1 & 10kΩ),*
  *Asahi (carbon paste 100Ω to 200kΩ),*
  *Electra (carbon paste 100Ω to 1MΩ),*
  *Dupont (*$LaB_6$ *ink to be screened on the back of copper foil)*
  - ✓ additive process
  - ✓ drawbacks:
    - tolerance : ± 10, 25, 40%
    - TCR: up to 700 ppm/°C
    - limited range of temperature
    - humidity sensitive
    - compatibility with RF requirements to be checked
    - some proprietary processes

- chemical additive deposition: *MacDermid*
  - ✓ additive process
  - ✓ chemical deposition of NiP layer
  - ✓ 25 to 100 Ω/sq with tolerance ≈ 10 to 15%
  - ✓ compatible with laser trimming



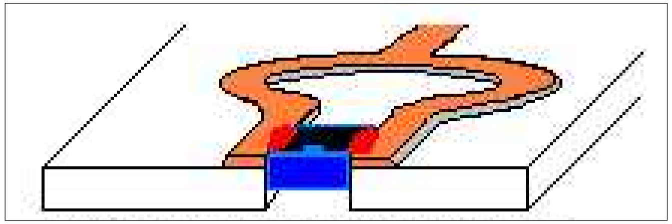



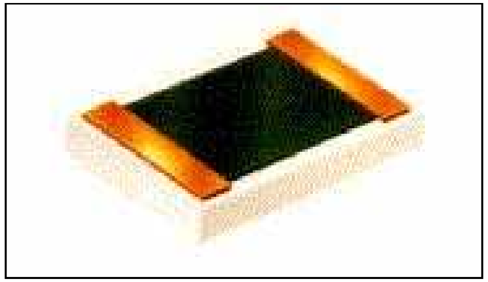
# more on materials: resistors



## resistor chips

- ✓ chip added in the thickness of the board (with relative thicknesses to manage)
- ✓ tolerance on the chip : up to 1%
- ✓ compatible with process for multilayer boards assembly at temperature of 220°C





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- materials and manufacturers: substrates, prepregs, resistors
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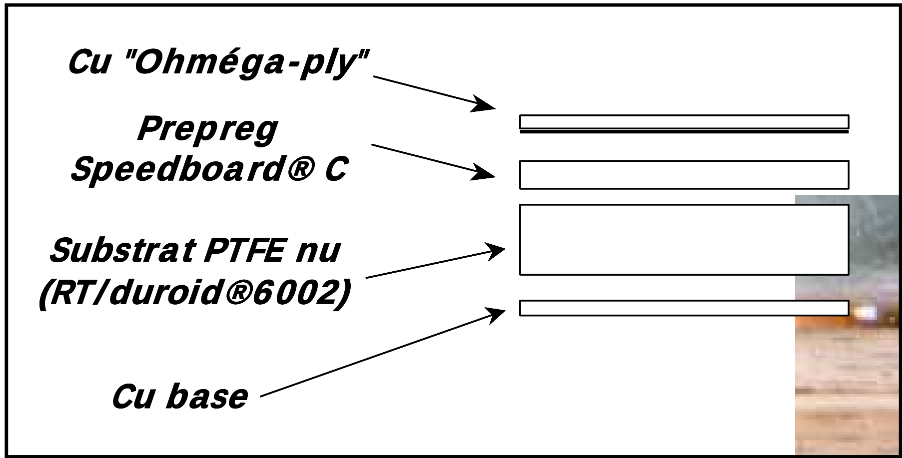
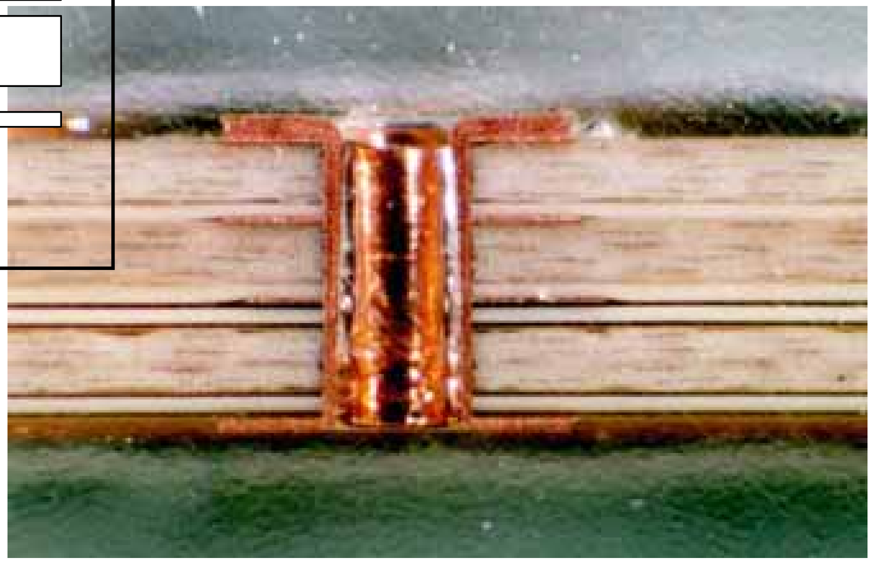
# existing solution for RF multilayer boards



- technology used for BFN (Beam Forming Network)




first step

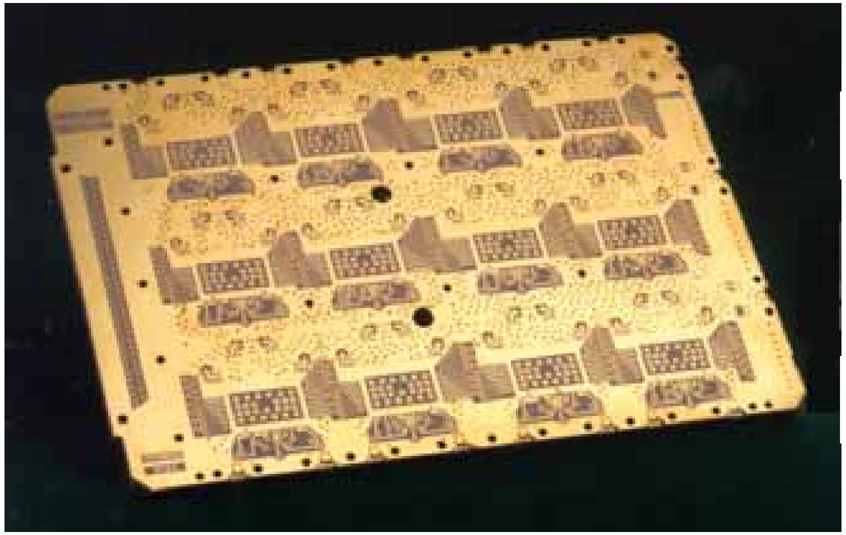


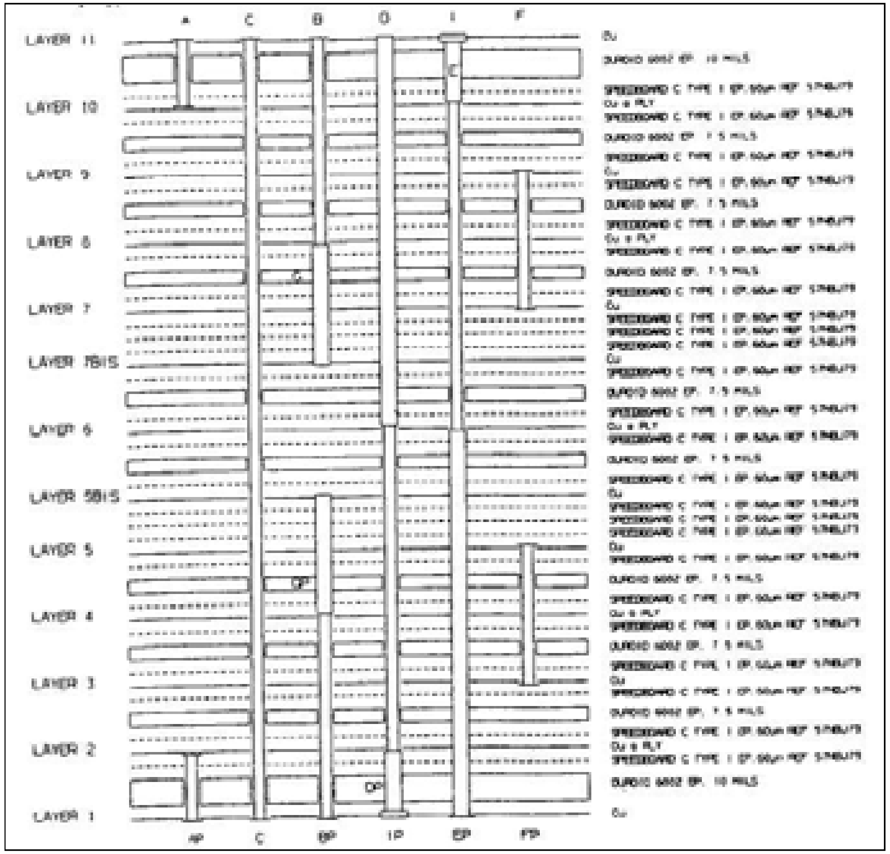
stripline

# existing solution for RF multilayer boards



## BFN for Stentor






- operating frequency : 5-15 GHz
- 265 x 165 mm
- up to 12 layers
- about 120 embedded resistors
- high reliability for space environment

# existing solution for RF multilayer boards



## limits of the existing process

- ✓ cost of raw materials
- ✓ mechanical stability of layers: unwoven PTFE substrate
- ✓ sequential board with complex assembly process
- ✓ cladded Ohméga-Ply non available for small quantities
- ✓ higher frequencies to be planned

| Thermoplastics (PTFE) | Thermosets |
|---|---|
| ☺ low losses | ☺ good thermo-mechanical stability |
| | ☺ "FR4-like" manufacturing processes |
| ☹ poor thermo-mechanical stability | ☺ homogeneous associated prepreg with low bonding temperature |
| ☹ prepreg with high bonding temperature | ☺ low cost |
| ☹ require specific manufacturing processes | ☹ higher losses than thermoplastics |

# agenda



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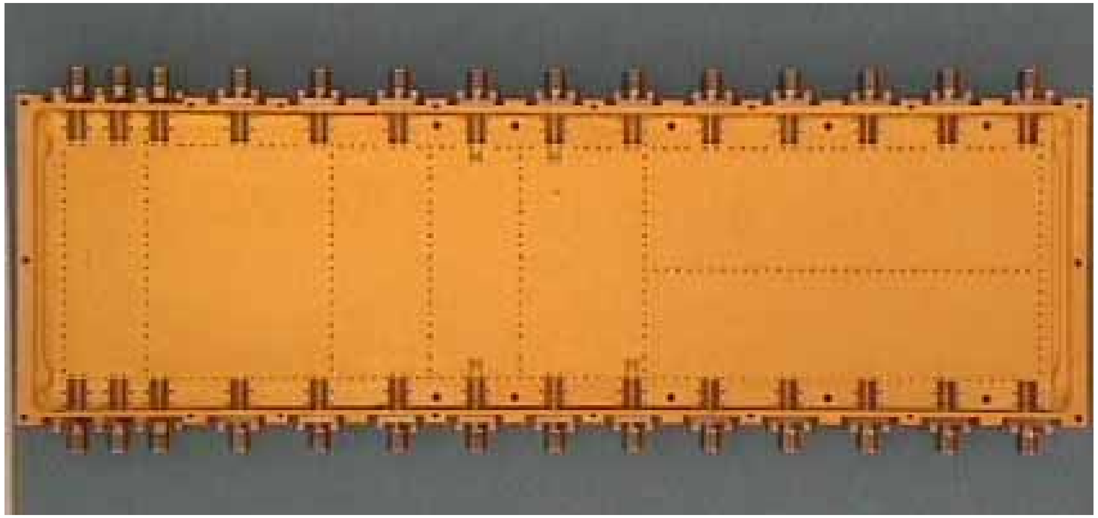
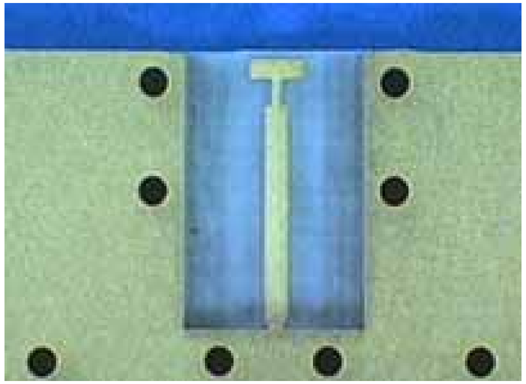
# thermoset multilayer boards



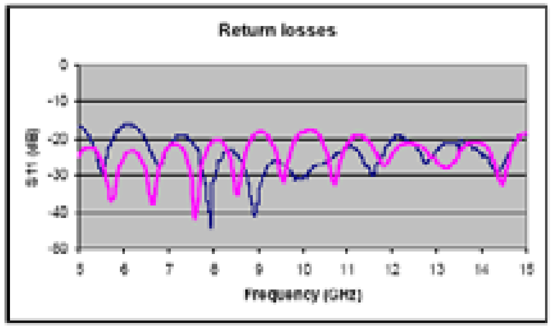
- 6 layers boards

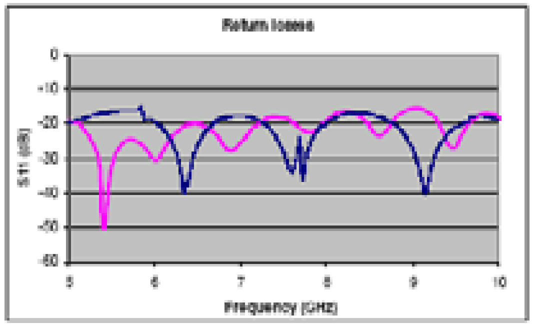


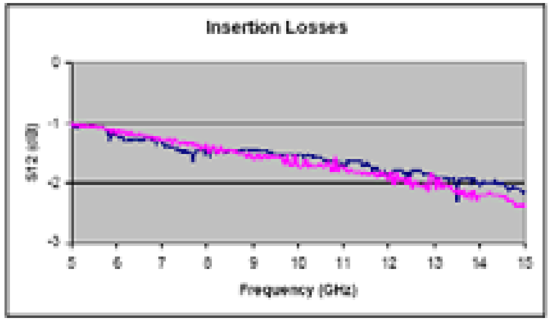
- RF interconnections
  - ✓ plated through holes and laser microvias for inner connections
  - ✓ RF openings for external interconnections
    - good reproducibility
    - mechanically and laser machined with tight tolerances at the PCB shop

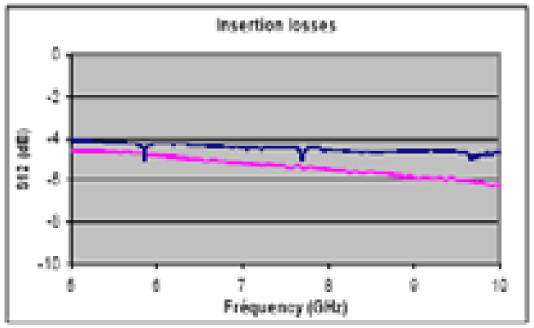


- electrical measurements

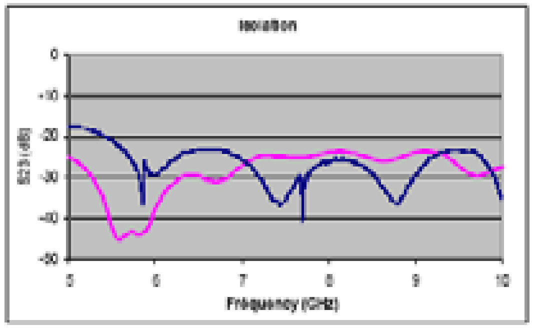



S parameters measurements of a 50 Ω line in stripline configuration (top) and a Wilkinson power divider (right) on a 3 layers PTFE-based (blue line) and a 6 layers thermoset-based (pink line) RF PCB.



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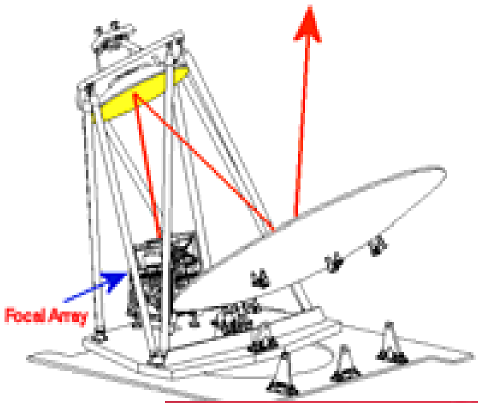
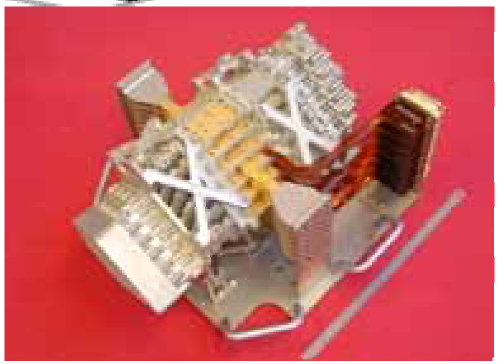
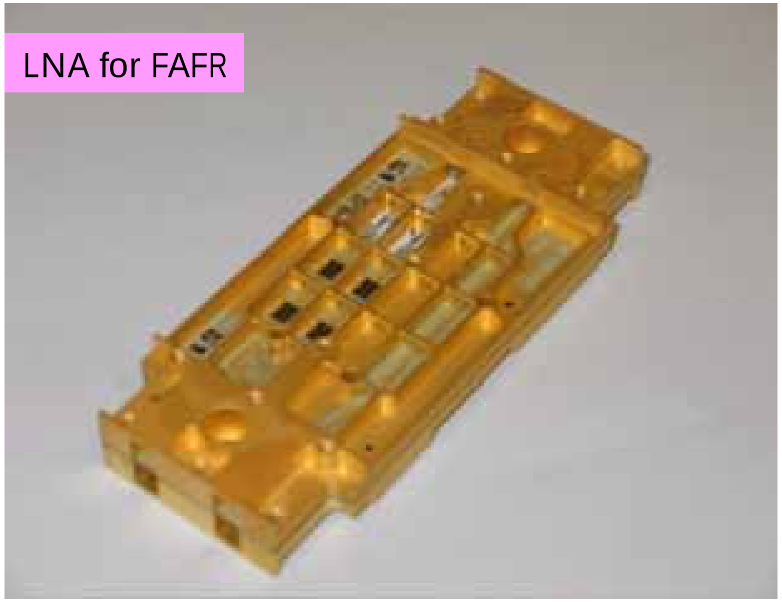
# double sided board



- needs for FaFr antenna (Focal Array Fed Reflector)
  - ✓ 30 GHz LNA compliant with antenna pitch
  - ✓ low volume, low weight






**62 x 25 mm - 25 g**

# FaFr: qualification model

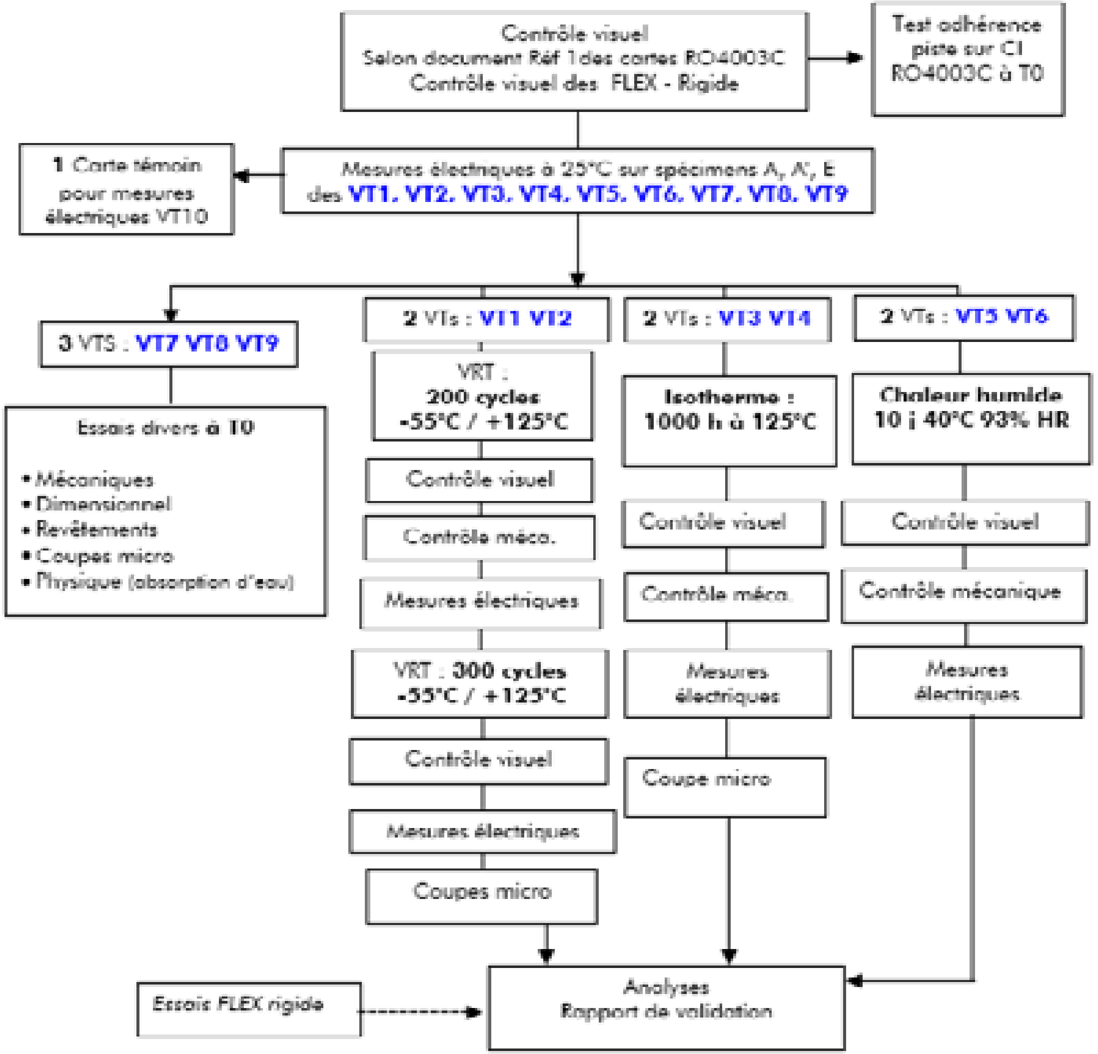


## main characteristics

- ✓ substrate RO4003, double sided, to be bonded on half aluminum body
- ✓ compatible with fine pitch and high accuracy lines
- ✓ compatible with gluing of MMICs and wire bonding
- ✓ without embedded resistors
- ✓ tight accuracy on mechanical shape, holes for location
- ✓ …

# FaFr: test plan for PCB







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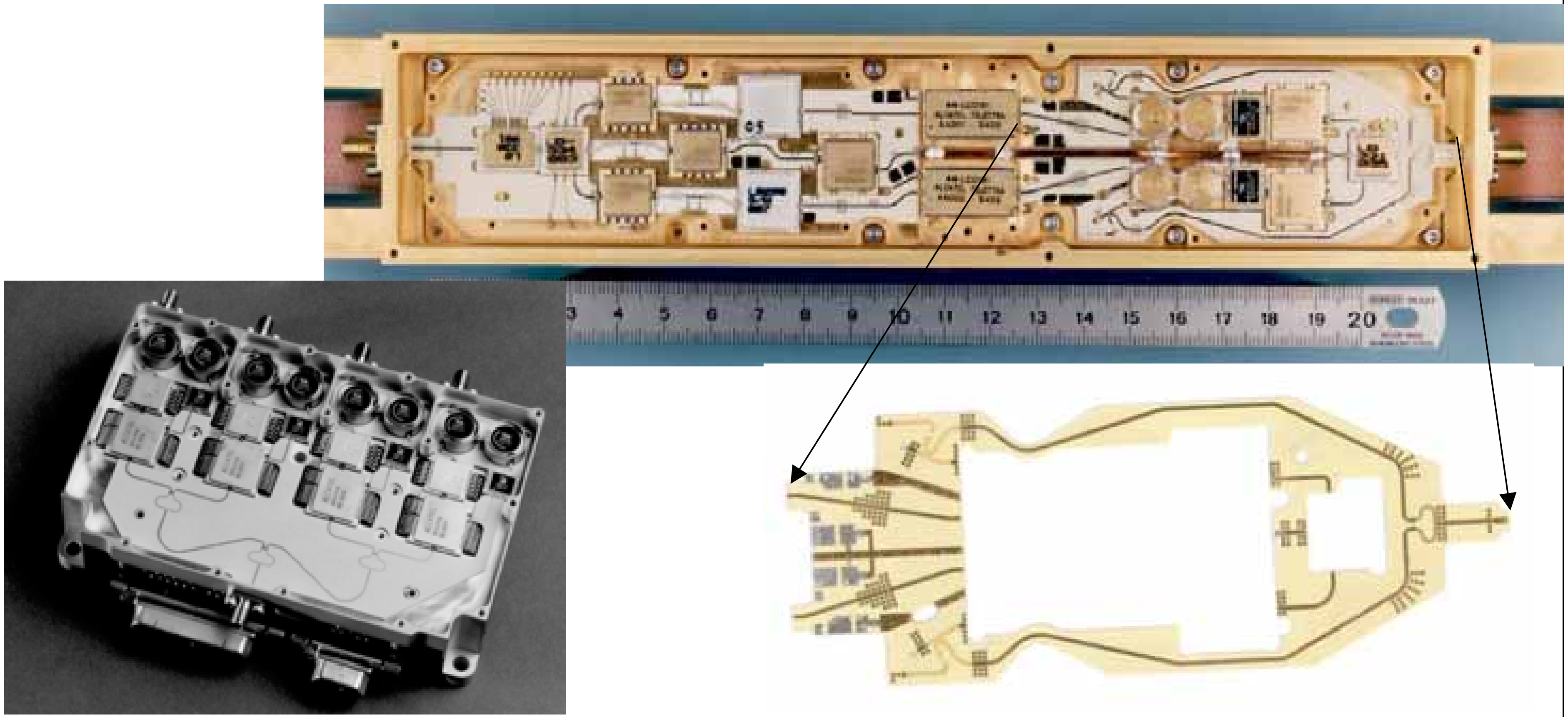
# organic RF PCB: not so new



- In the 90s… TMM10i as double sided RF boards



# thanks

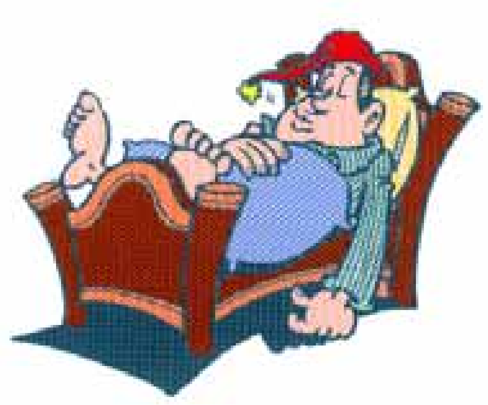


- to the Packaging Interconnection Group :
  - ✓ Chloé Schaffauser
  - ✓ Philippe Monfraix
  - ✓ Mathieu Paillard
  - ✓ Olivier Vendier
  - ✓ Laurent Garcia
- to agencies : CNES, ESA
- to EC

# and now, any question ?



## thanks for your attention



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