THALES

Low-power/ high-power SPACE qualified RADAR TWTs For earth observation

Ernst Bosch*, Philip Birtel*, Martin Albrecht*
Julien Degremont**
*) THALES Germany GmbH/ Ulm / Germany
**) Thales AVS Vélizy / France

Pulsed TWT - recent success for MIS

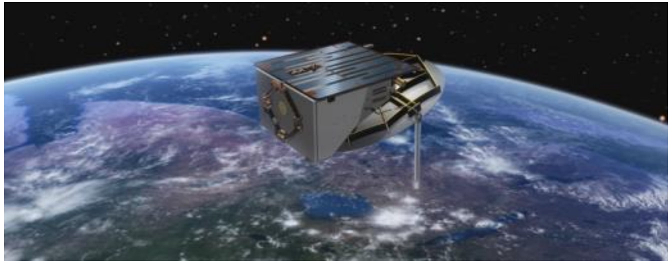
CFOSat

- SWIM Altimeter
- Ku-Band TL 14140 from Thales MIS
- Project in cooperation with CAST
- Altimeter instrument coordinated by CNES

Picture : courtesy from CNES – Jan 2018

German classified Program

- 2 generation of SAR military satellites
- High power X-band TWT
- First satellites still in perfect operation after 12 years
- On-going project to be launched soon with Thales TWT

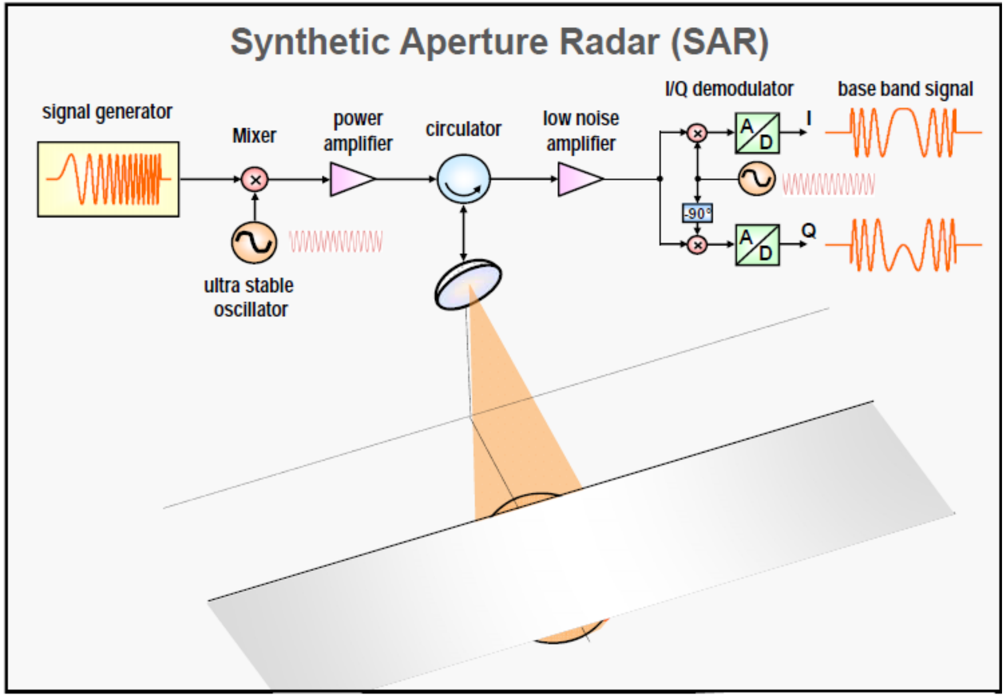


Agenda

- Background Space Radar and Application
- MIS Heritage and performance
- Design criteria for Radar TWTs
- MIS Opportunities for pulsed TWTs
- Conclusion

Pulsed TWT for SAR application

- High resolution capability (independent of flight altitude)
- Weather independence (depending the frequency range)
- Day/night imaging capability (own illumination)
- Complementary to optical systems
- Polarization signature can be exploited (physical structure, dielectric constant)



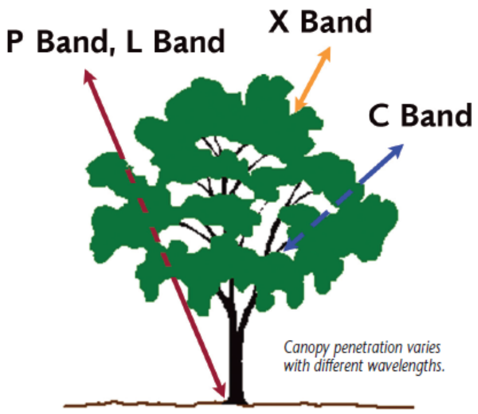
Great interest from the scientific community (spectrometer, altimeter…) as well as the commercial community (military, enterprise, agriculture, disaster management…)

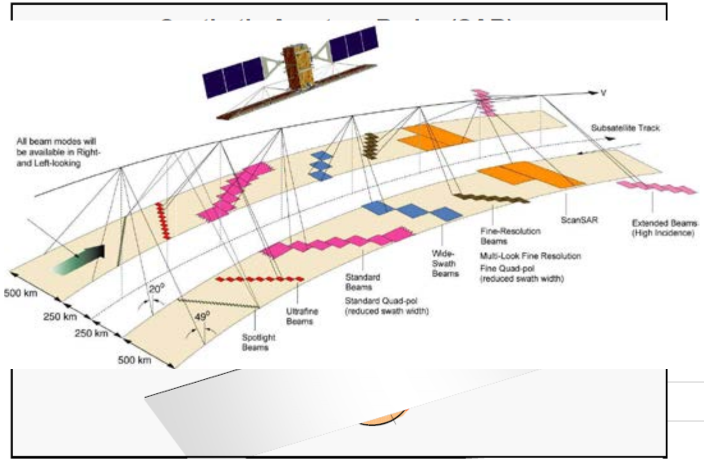
Usage of pulsed RF from space

Frequency band	*Frequency range*	*Application Example*
• VHF	300 KHz - 300 MHz	Foliage/Ground penetration, biomass
• P-Band	300 MHz - 1 GHz	biomass, soil moisture, penetration
• L-Band	1 GHz - 2 GHz	agriculture, forestry, soil moisture
• C-Band	4 GHz - 8 GHz	ocean, agriculture
• X-Band	8 GHz - 12 GHz	agriculture, ocean, high resolution radar
• Ku-Band	14 GHz - 18 GHz	glaciology (snow cover mapping)
• Ka-Band	27 GHz - 47 GHz	high resolution radars

SAR surface

Infrastructure (pipline,..



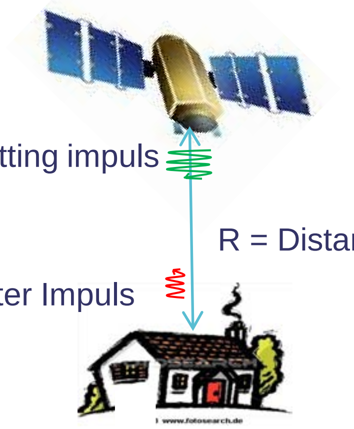


- Complementary to optical systems
- Weather independence (depending the frequency range)
- Day/night imaging capability (own illumination)
- High resolution capability (independent of flight altitude)

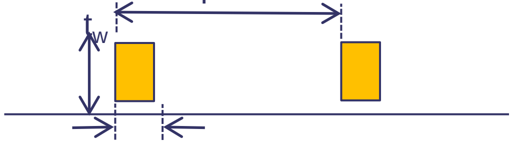
THALES

Pulsed TWT for SAR application- Basics

Why high Peak Power?



Avg transmitting pulse power



$$P_{Savg} = P_S \times t_d / t_w$$

Radar equation

$$P_E = \frac{P_S \times G^2 \times \lambda^2 \times \sigma}{(4\pi)^3 \times R^4}$$

P_E = power of reflected beam (recieved)
P_S = power of transmitted pulse
R = Distance Satellite earth

The transmitted siggnal get an attentuation of R^4
Lead to reduced signal P_E

The distance equation can be foolwed like:

$$R_{max} = \sqrt[4]{\frac{P_{Savg} \times G^2 \times \lambda^2 \times \sigma}{(4\pi)^3 \times P_{Emin}}}$$

P_{Savg} . Avg transmitted signal
P_{Emin} min. recieved signak

The avg Power of the pulsed signal define the potential reachable distance of the radar system and the Pulse peak power for the pulse quality

Pulsed TWT for SAR application- Basics

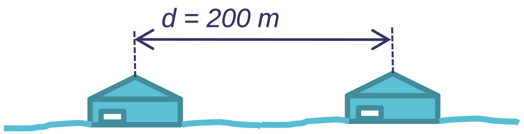
Why large Bandwidth?

The resolution of a radar is defined by the Pulse length τ (sec)

$$D\,(m) = c_0 \times \tau / 2$$

c_0 = light velocity= 3 x 10 ^{8} m / sec

example $\tau = 2$ µsec ***D = 300 m***
$\tau = 4$ µsec ***D = 600 m***



These houses cannot be detected as separate houses of this radar system

=> because D > d !

The pulse compression method can improve the resolution of the radar system!
The transmitting pulse (frequency) will be modulated within the bandwidth for SAR system

$$D\,(m) = c_0 / (2 \times BW)$$

BW = bandwidth of the transmitter:

Example:	*BW = 100 MHz*	***D = 1.50 m***
	BW = 200 MHz	***D = 0.75 m***

Both houses can be detected with a high resolution because D < d !

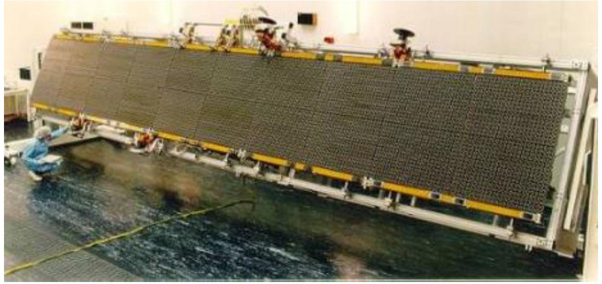
=> High bandwidth => high resolution

THALES

Today´s SAR technologies for amplification

High Power TWTA or Klystron
100's of Watts to kW's
Very high efficiency
Still best solution for high power

Suitable for single-HPA antennas
=> ERS-1 & 2, SAR German Program, Asnaro-2...



Gallium Arsenide (GaAs)
<20 Watts
Getting replaced by GaN
<30% efficient

Suitable for highly distributed antennas
=> ASAR, TerraSAR X, PAZ...

Gallium Nitride (GaN)
10's-100's of Watts
Medium efficiency (30-50%)
Good for low frequencies

Suitable for distributed antennas with T/R modules and small satellites
=> NovaSAR-S, ICEYE, CSG-X, Capella..

OPEN

THALES

SAR Resolution

Active array antenna

High Resolution SpotLight
- Up to 1 m resolution,
- Span size 10 km (W) × 5 km (L)

StripMap
- Up to 3 m Resolution
- Span size 30 km (W) × 50 km (L)

ScanSAR
- Up to 18 m resolution,
- Span size 100 km (W) × 150 km (L)

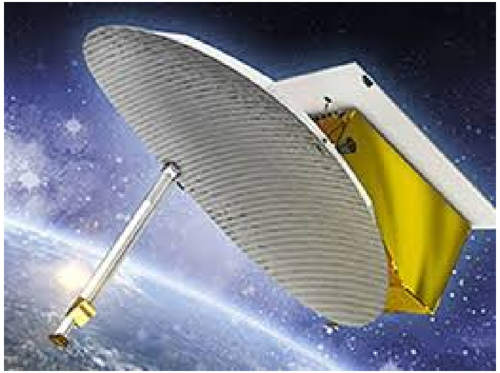
Life time ~ 5 to 7 y

Single source reflector

HighResolution SpotLight
- Less than 0,5m resolution
- Span size 5,5 km (W) x 5,5 km (L),

ScanSAR
- Up to 1 m resolution
- Span size 60km (W) x 8 km(L)

Life time ~ 5 to 7 y



Distributed antenna

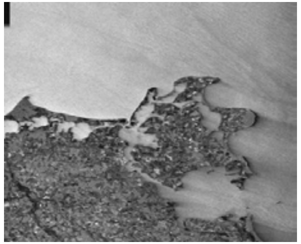
- **Same as for active antenna**

Thales MIS pulsed TWTA in their special application

Synthetic Aperture Radar (SAR):

TL 5500, TL 14070, TL 9xxx, TL14140

=> ERS1&2, Radarsat, X-Sar,



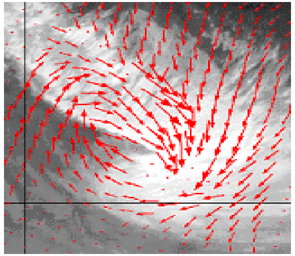
Scatterometer &Altimeter:

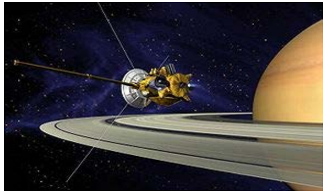
TL 5500 => ERS 1&2 Radarsat

TL 9300, 9700: X-Sar, calssified projects

TL 14060, TL14140

- => ERS 1&2, Ocenasat, HY2,WSOA, OVWM, FY-3, Swim, CFOsat





Frequency Band	Total Nb of Units delivered	Total Nb of In-Orbit Hours (Thousands of Hours)
pulsed	>45	> 1200

Bildquelle: ESA / JPL

MIS View for segmentation and market needs for TWT(A)

TWT → Power

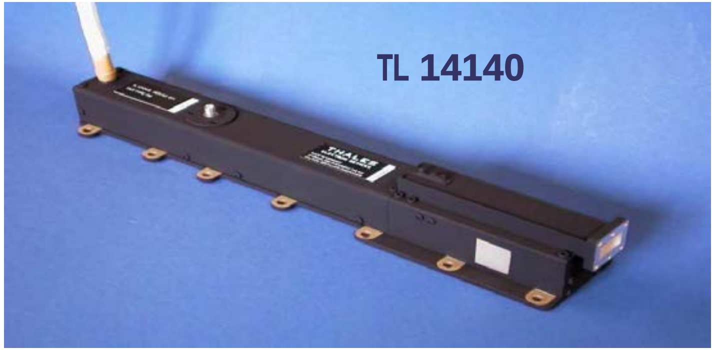
150 W | 300 W | 500 W | 1kW | 2 kW | 3kW | 4 kW | 4,8 kW | 6 kW

Low power TWTAs	Medium power TWTAs	High power TWTAs
High duty cycle	Medium duty cycle	Low duty cycle
<u>Applications</u> • Altimeter • Scatterometer • SAR With single or combined TWTAs	<u>Applications</u> • SAR • Earth observation (5 GHz) With single or combined TWTAs	<u>Applications</u> • SAR • Earth observation (5 GHz) 4.8 kW export limitation in X band With single or combined TWTAs
<u>Products</u> • TL 14140 (13 GHz 140 W) • Development capabilities	<u>Products</u> • BB´s in X & Ku • Development capabilities	<u>Products</u> • TL 9700 • Development capabilities

THALES

Technical Information

frequency:	13 - 14 GHz range
output power:	120 W min. (**TWTA**)
	135 W min. (**TWT**)
duty cycle:	40 % continuous
input power:	5 dBm max.
efficiency:	~57 %
helix voltage:	6.3 kV
mass:	< 800 gr



frequency:	9 - 10 GHz range
output power:	>4 kW.
duty cycle:	4 to 8 % continuous
input power:	33 dBm max.
efficiency:	~40 %
helix voltage:	14.5 kV
mass:	< 7,5 kg

OPEN

THALES

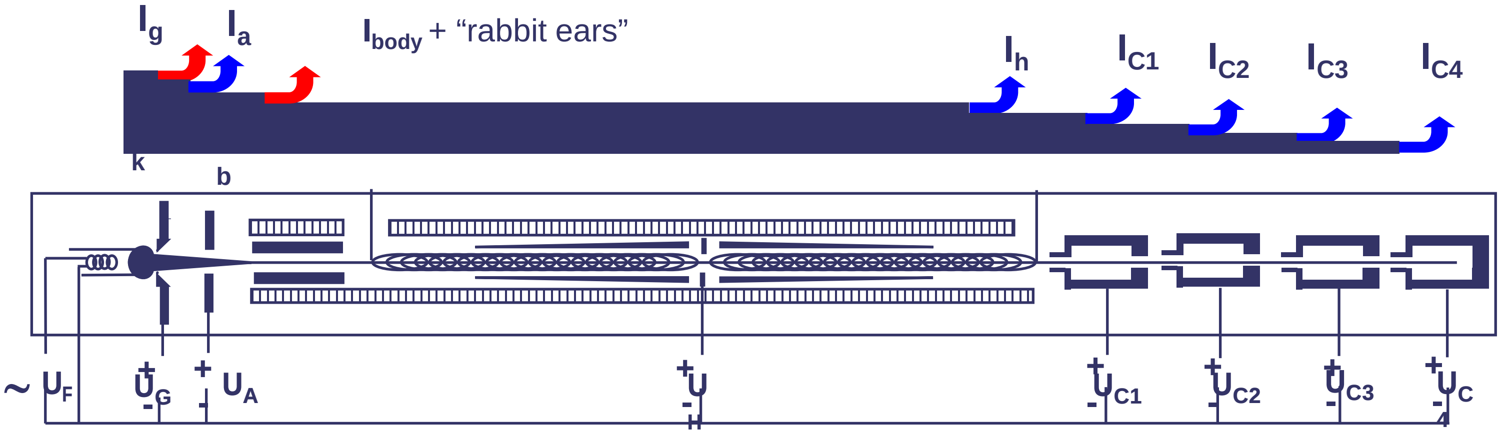
Why is a pulsed TWT design more difficult compared to CW TWT and where the critical elements?

- PP TWT has no cathode current regulation possibility over temp. and life
- PP TWT needs grid steps for constant emission behaviour
- EPC grid modulator instead of anode voltage regulator
- PP TWT more temperature sensitive than CW TWT
- PP TWT more vibration sensitive than CW TWT -> grid
- PP TWT shorter life than CW TWT
- PP TWT high grid voltage sensitivity factors
- PP TWT different current distribution
- EPC TM / TC different

- Duty cycle limitation due to grid- thermal loading
- PRF limitation due to “rabbit ears”
- Pulse length limitation due to grid thermal capacity and EPC stability
- Life limitation due to max. possible grid steps (max 4 steps)
- Life limitation due to thermal / mechanical stress

Operation condition for pulsed TWT/A

TWT Currents



= currents in CW TWT

= currents in grid modulated TWT
I_{body} / rabbit ears / I_h not separated
and measured as “helix” current

THALES

Operation condition for pulsed TWT/A

Helix Current TWT

Caused by defocused electron beam during grid voltage transients.

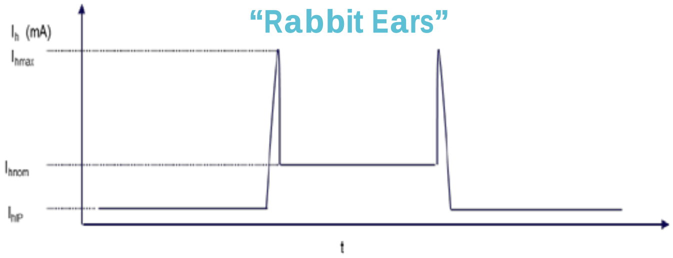
At sat drive typical $I_{h\ maxsat} = 4$ to $6 \times I_{h\ nomsat}$

At zero drive typical $I_{h\ maxzero} =$ up to $10 \times I_{h\ nomzero}$

$I_{h\ maxzero}$ roughly equal to $I_{h\ maxsat}$

I_{hIP} = helix current during interpulse

“Rabbit Ears”



On EPC level additional parasitic currents

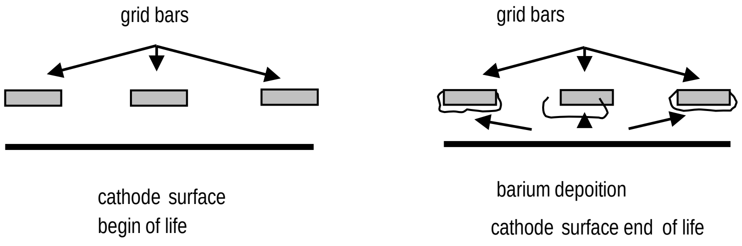
$I_p = C \times dU_g / dt$

C = parasitic capacitance, e.g. high voltage cable, grid/cathode etc

U_g = grid voltade

Grid Life Effects

barium deposition on grid bars with life

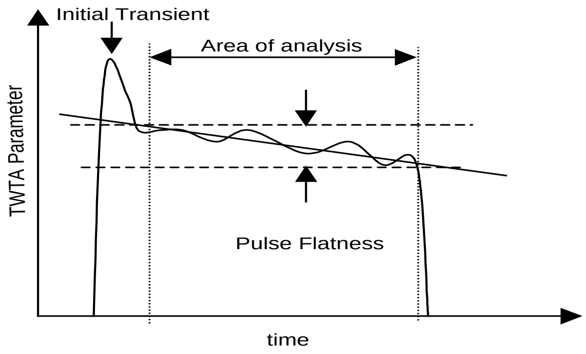


End of life

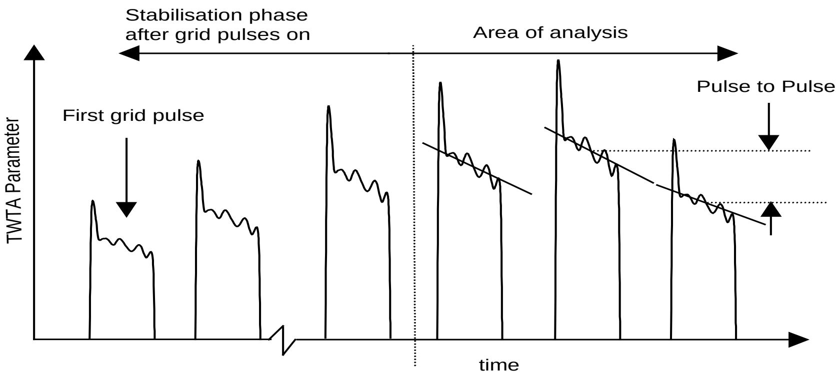
Operation condition for pulsed TWT/A

TWTA Pulse Stability

In Pulse



Pulse to Pulse



Design

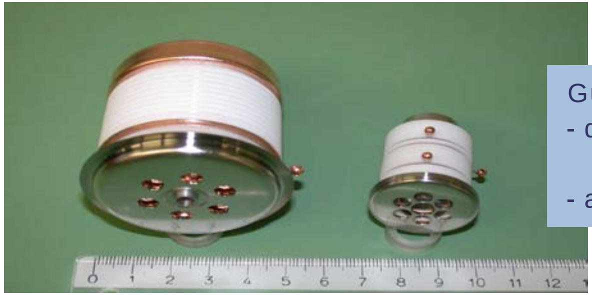
Design Criteria

- High power
- Life effects
- Thermal behaviour

Gun:
- space qualified
- ceramic stack design
  (size depending
  on power class)
- MM-cathode
  (cathode loading1,4- 2 A/cm²)
- intercepting grid

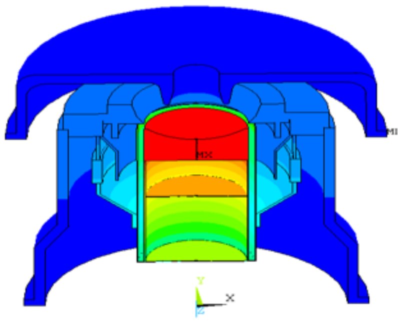
Delay Line:
from existing (non) space tube according RF-requirements

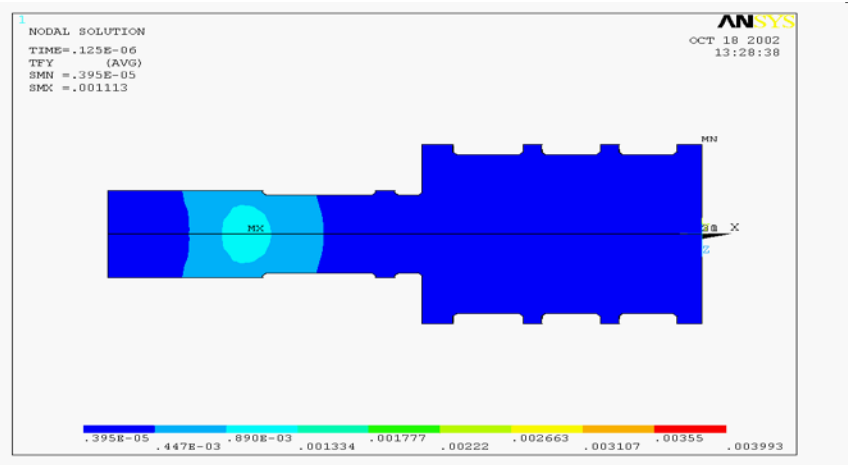
Collector:
- space qualified
- multi stage design
  (size depending
  on power class)
- electrostatic or
  magnetic focussed

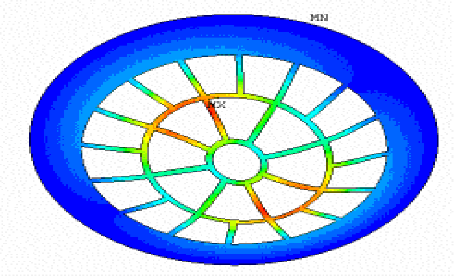


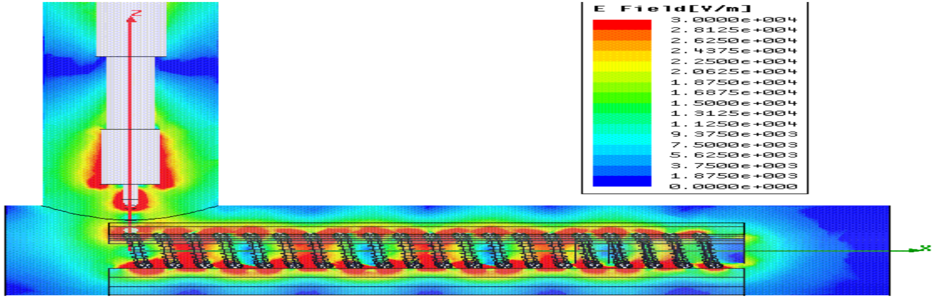
Gun & Collector
- dominating for life
  ⇒ **space qualified design**
- adaptation of electron optic

Examples of Anysis Simulation for thermal constrains









THALES

Potential reachable Peak power/performance

L-	•280 W peak power, 40 % duty cycle, based on CW TWT 300 W •Development needed
S-	•450 W peak power, 30 % duty cycle, based on CW TWT 500 W •Development needed
C-	•Old design up 5 kW, Redesign to actual design- proposal made up to 4 kW •Low power 150 W, 30 % duty cycle, based on CW TWT 150W •Development needed for both designs
X-	•High power up to 6 kW in production, exportable version up 4,8 kW (same TWT) •Low power 150 W, 30 % duty cycle, based on CW TWT 160W •Development needed for low power
Ku-	•Medium power up to 2,,5 kW based on X-Band Design •Low power 280 W, 30 % duty cycle, based on CW TWT 300W •Development needed for both designs
Ka-	•High power up to 1,5 kW (baseline ground radar TWT) •Low power 130 W, 30 % duty cycle, based on CW TWT 140W •Space qualification for high power design, development for low power design

THALES

Conclusion

Radar applications for Space

- Reflector antenna application still of high interest in case of high resolution (C-X-Ku Band, new Ka)
- Unfortunately no regular need spread over the years

MIS has a large experience for pulsed on ground

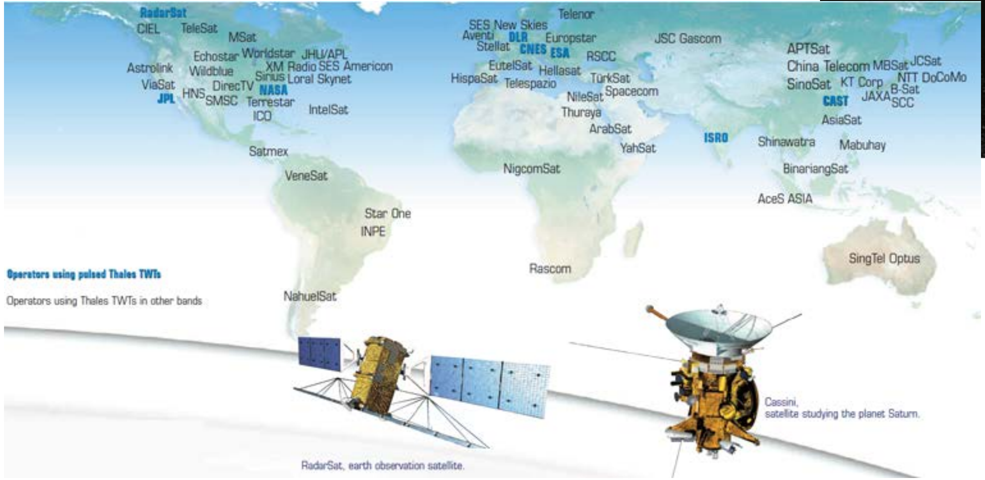
- Definition of pulse TWTs design for low and high power
- Heritage and experience for new developments
- 1 to 4 TWTAs per satellite

MIS is well prepared for all new space radar market

MIS has delivered several programs for medium power in Ku-Band for SAR, Scatterometter or altimeter)

- power portfolio up to 120 W
- Frequency and power potential based on CW Space TWTs
- New medium power pulsed TWTs can be derived from CW Space TWTs

Thanks for your attention !!!!



OPEN

THALES