RF Sub-Systems for Cargo and Vehicle Inspection

D.J. Mistry, T.A. Cross, C.R. Weatherup

Presented by Trevor Cross, Group Chief Technology Officer
e2v Technologies (UK) Ltd.

e2v technologies

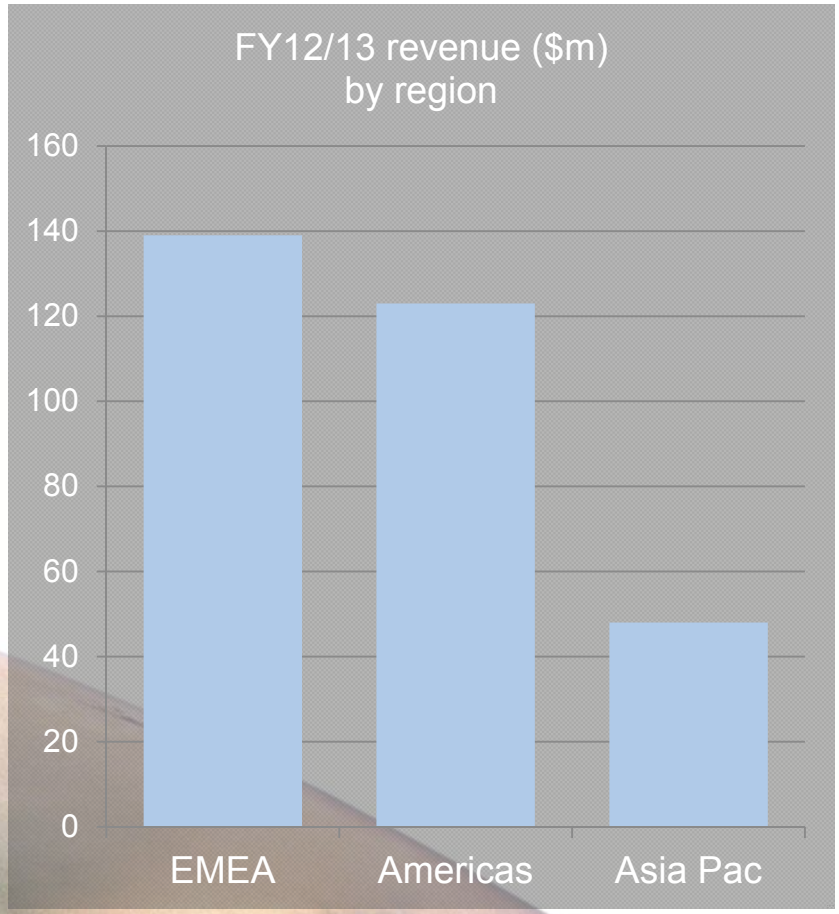
Founded in **1947**

>$300m annual sales

1600 employees

500+ engineers & scientists

Operational facilities in
Europe, the US and Asia



e2v – technologies

We aim to deliver enabling technology and vital services for critical systems

Our business is built on our core high performance technologies rooted in:

- **Vacuum electronics - generation and control of RF and microwave power**
- **Silicon photonics – image sensors & detectors**
- **Specialist hi-rel digital IC design, manufacture, package, test and life cycle support**

Our strategy includes a move from a component to a sub-system scope of supply, with long term support and service.

Overview

1) Security Screening Market
2) X-ray Sources
3) Linac screening systems
4) RF Sub-systems
5) Summary

1) Security Screening Market

2) X-ray Sources

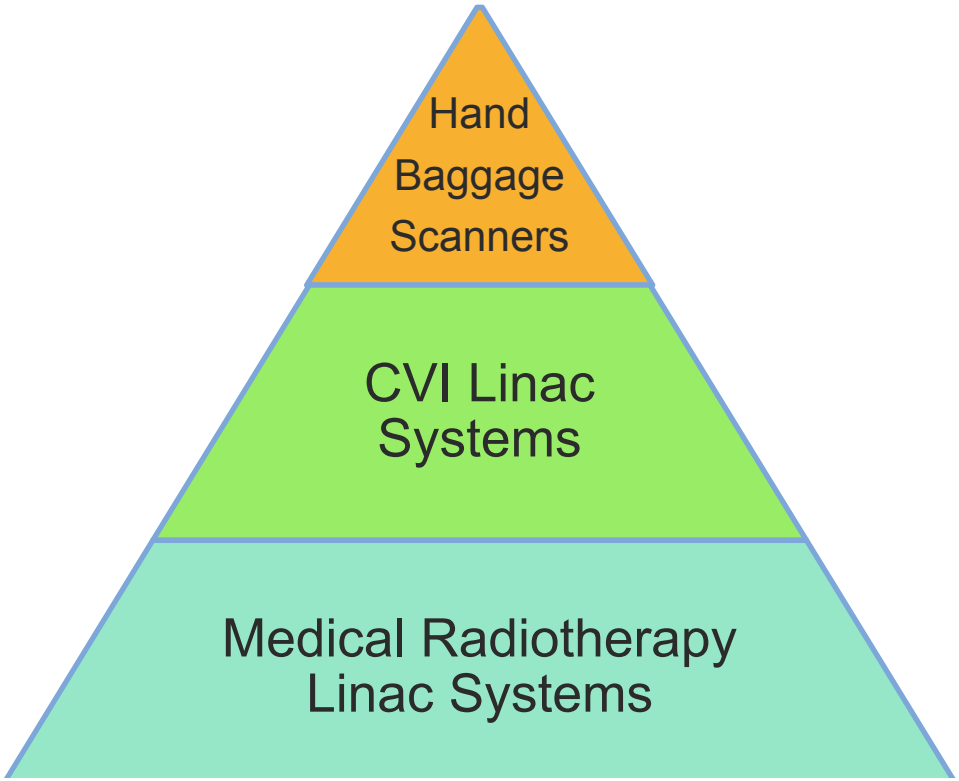
3) Linac screening systems

4) RF Sub-systems

5) Summary

Security Screening Market

Some significant specialist applications of X-rays and accelerators



Indicative system costs

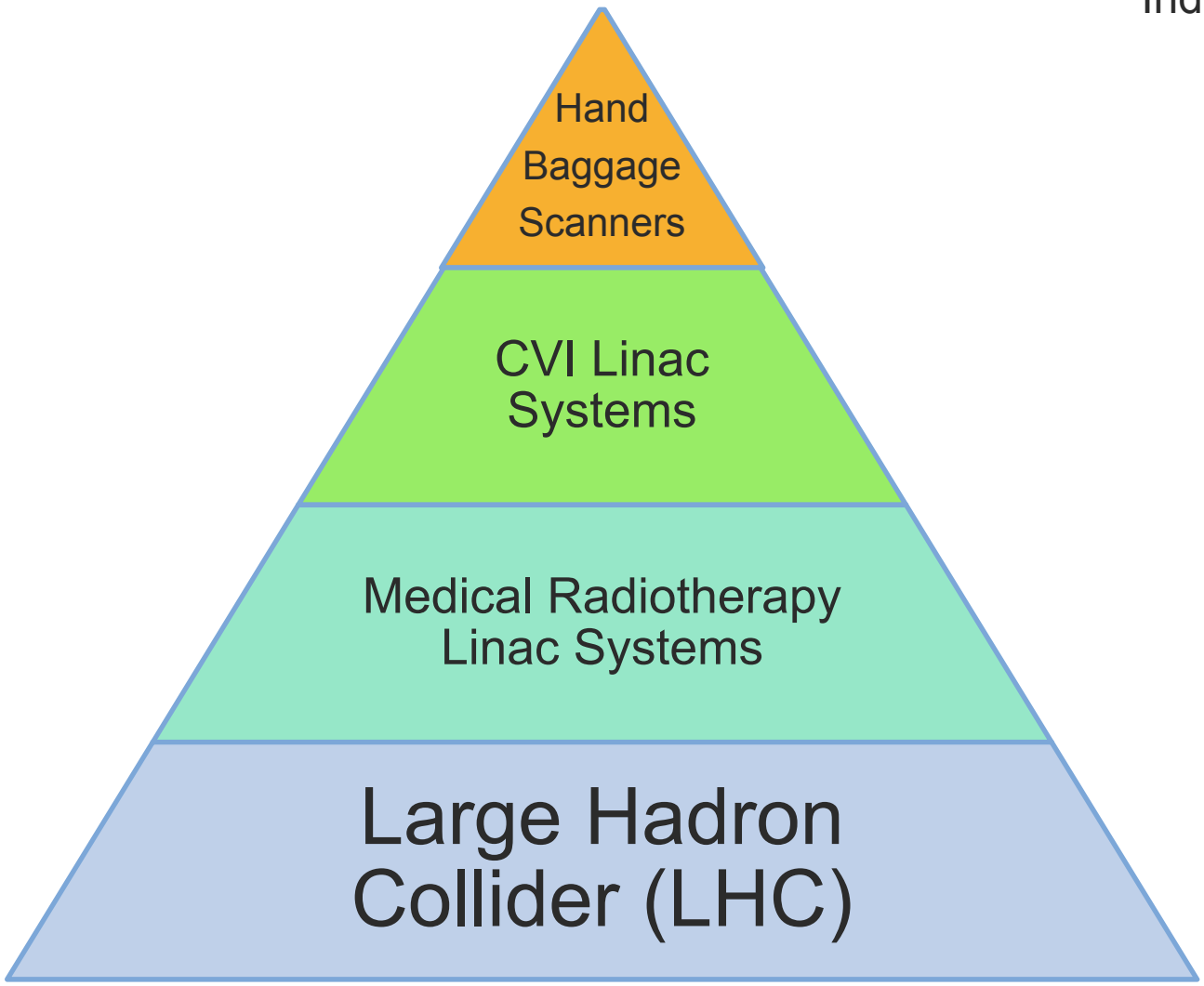
<$100k

~$1m

~$4m

Security Screening Market

Some significant specialist applications of X-rays and accelerators



Indicative system costs

<$100k

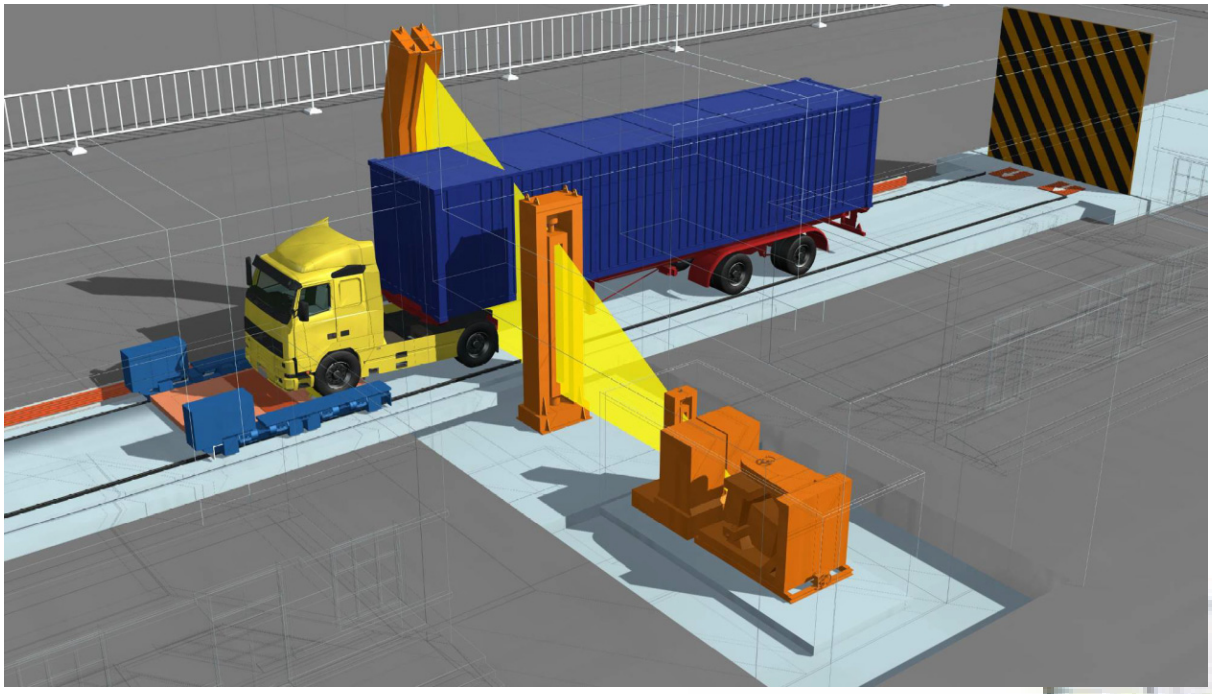
~$1m

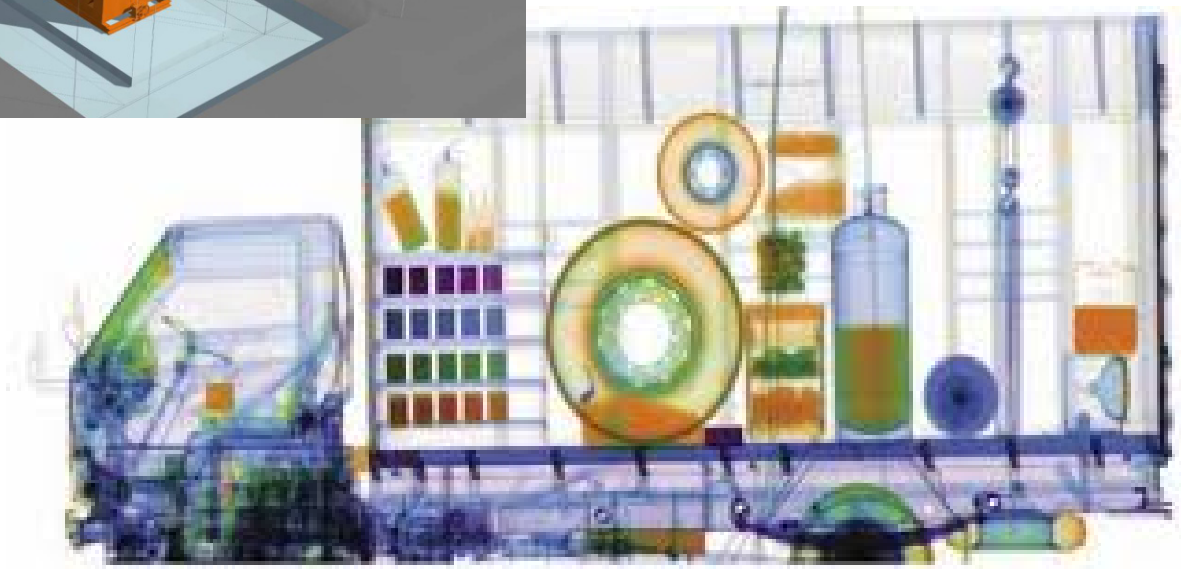
~$4m

~$5bn

Cargo and Vehicle Inspection ('CVI')

- a subset of security screening



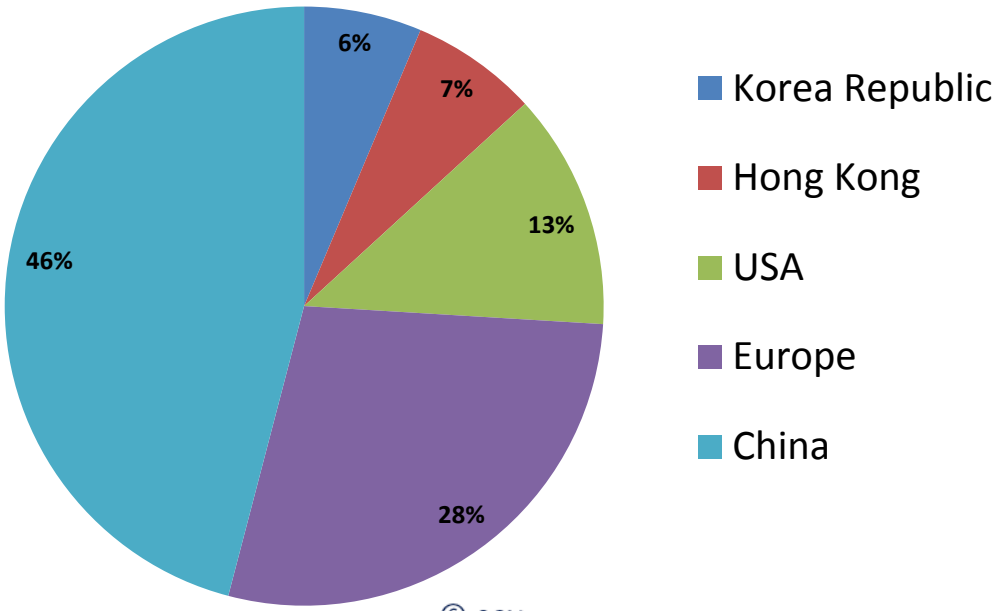


Security Screening Market
Container Traffic

- Over 90% of world's non-bulk cargo transported in standardised containers.

- Over **600 million** container shipments each annum.

Container Shipments by Country



Source containerisation international yearbook, 2014.

The threats ……

Image Credited to L3 Communications Security & Detection Systems [f13]

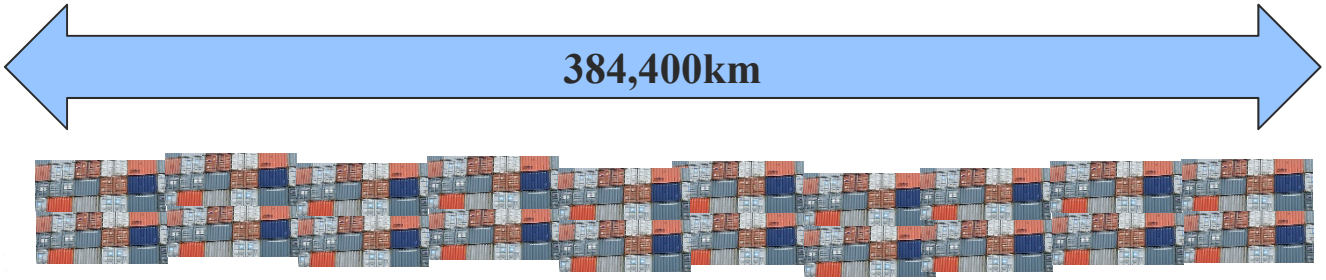
What's in the containers ?

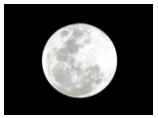
What it says on the paperwork ?

OR

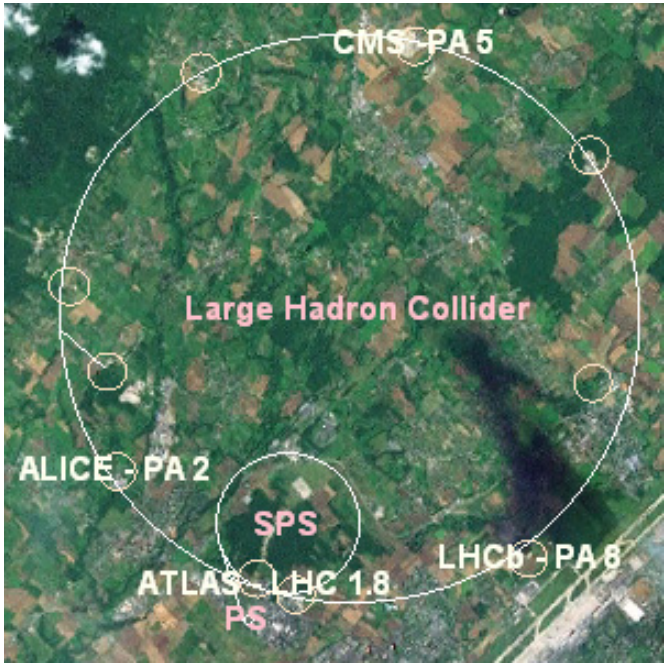
- Contraband ?
- Terrorist material ?
- ????

Container screening - the scale of the problem …the containers shipped in one year..





Containers stacked 9 high …. would still reach the moon !



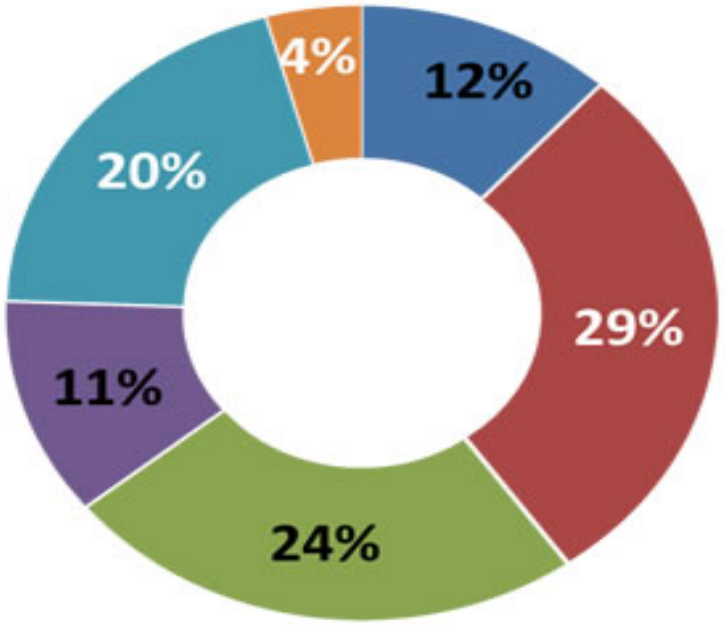
…. or lined up end to end they would go ~ 278,000 times around the LHC tunnel !

Image credits: Wikipedia; CERN

Security Screening Market

X-ray security screening market segmentation

- The global X-ray security screening market is forecast to grow from $1.2 billion in 2011 to $1.9 billion by 2016.
- Over the next five years, analysts forecast a CAGR growth of 7% of the global X-ray screening market



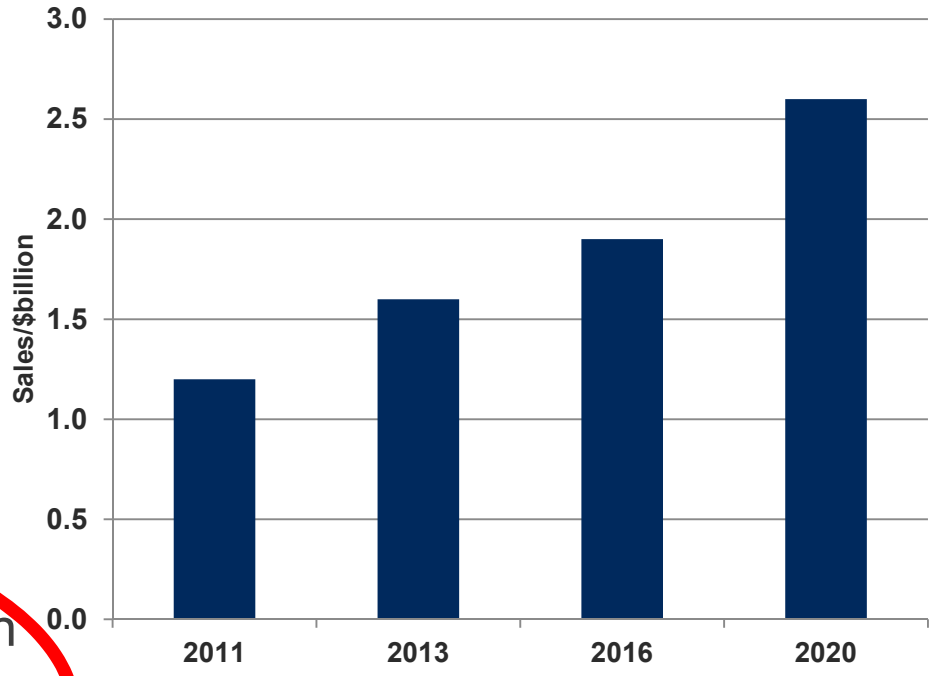
Airport-cabin baggage	29%
Secured facilities	24%
Postal items	11%
Supply chain cargo	20%
People screening AIT	4%
Air cargo	12%

Source: Homeland Security Research Corporation 2011

Security Screening Market
Growth rate

Growth in X-ray security screening due to:

- Expansion of Asia Pac secure facilities and aviation security markets
- Replacement of more than outdated X-ray systems
- There is no modality on the horizon that can competitively challenge the cost-performance of X-ray based screening technologies.



Global X-ray security screening market including system sales and aftersale revenues

Source: Homeland Security Research Corporation 2011

Security Screening Market
Baggage and Mail Scanning - examples

Image credited to Westminster International LTD.WS IS100X[f5]

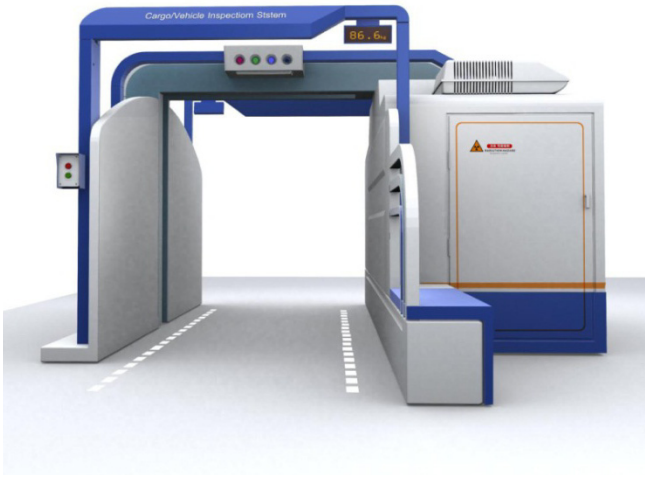
Image credited to Smith's Detection System[f6]

Image Credited to Lighthouse Global Technologies. [f8]

CX6040BI X-ray inspection system. Image Credited to Nuctech Company Limited [f9]

Image credited to L3 Communications Security & Detection Systems[f7]

Security Screening Market
- CVI Systems - examples



PB Series CVI System. Image credited to Nuctech MB series, [f11]

Image credited to Rapiscan. Eagle R60 Rail Scanning System [f10]

High Energy X-ray Mobile Screening System. Image Credited to Smith's Detection Systems. [f14]

Image credited to American Science & Engineering Sentry Z portal System [f12]

Security Screening Market
Solutions for Cargo and Vehicle Inspection

- Focus on security screening systems CVI.
  - which require a linac X-ray source, as these systems
  - Up to 10 MeV
- Derived from the accelerators and RF sub-systems used in radiotherapy
- Some unique cargo scanning imposes new requirements such as,
  - Portability, material discrimination

  And,
  - higher throughput, leading to a shorter time between object screening.

1) Security Screening Market

2) X-ray Sources

3) Linac screening systems

4) RF Sub-systems

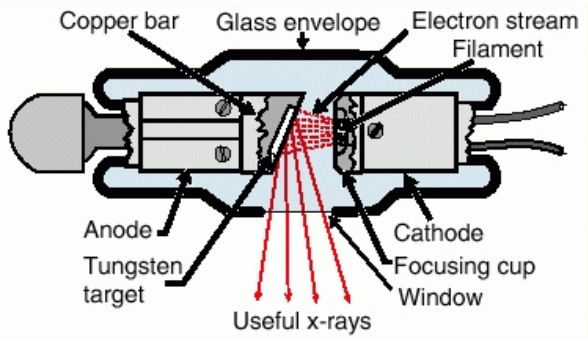
5) Emerging Technologies

6) Summary

X-ray Sources for CVI

- Choice is dependent upon the X-ray photon interactions required to obtain contrast in a particular application and detector performance.

- X-ray sources affect the screening systems capability in terms of:
  - Material discrimination
  - Throughput
  - Reliability
  - Safety
  - Cost and space requirements



X-ray Vaccum Tube. Photo Credits and Copyright 2007 Dorland's Medical Dictionary for Health Consumers. by Saunders

Cobalt-60 Source. Photo Credits and Copyright 1999: Oak Ridge Associated Universities)

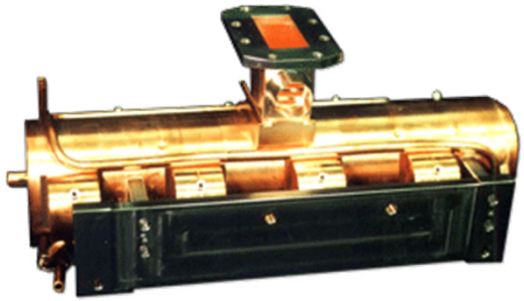
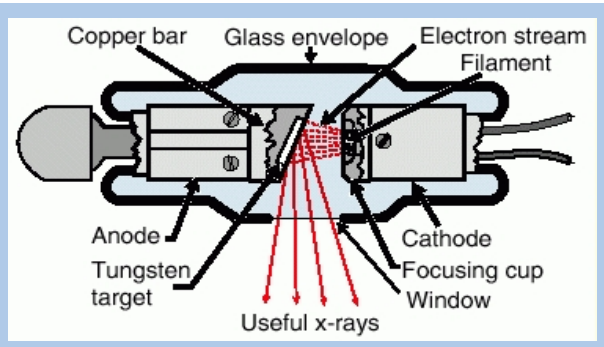


Image credited to AET, Inc.

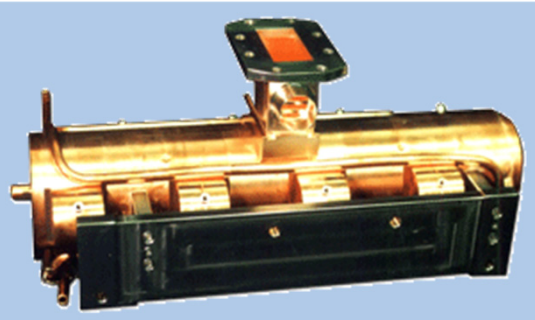
X-ray sources matched to systems

Source example



X-ray Vaccum Tube. Photo Credits and Copyright 2007 Dorland's Medical Dictionary for Health Consumers. by Saunders

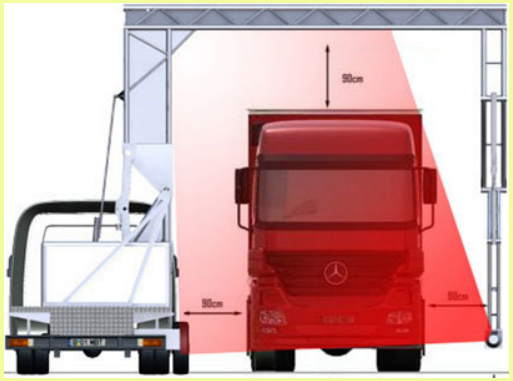
Cobalt-60 Source. Photo Credits and Copyright 1999: Oak Ridge Associated Universities)



6 MeV S-band Linac. Image credited to AET, Inc.

System example

CX6040BI X-ray inspection system. Image Credited to Nuctech Company Limited [9]



CVI Scanner. Image credited to Kapri Corp copyrighted 2010-2011

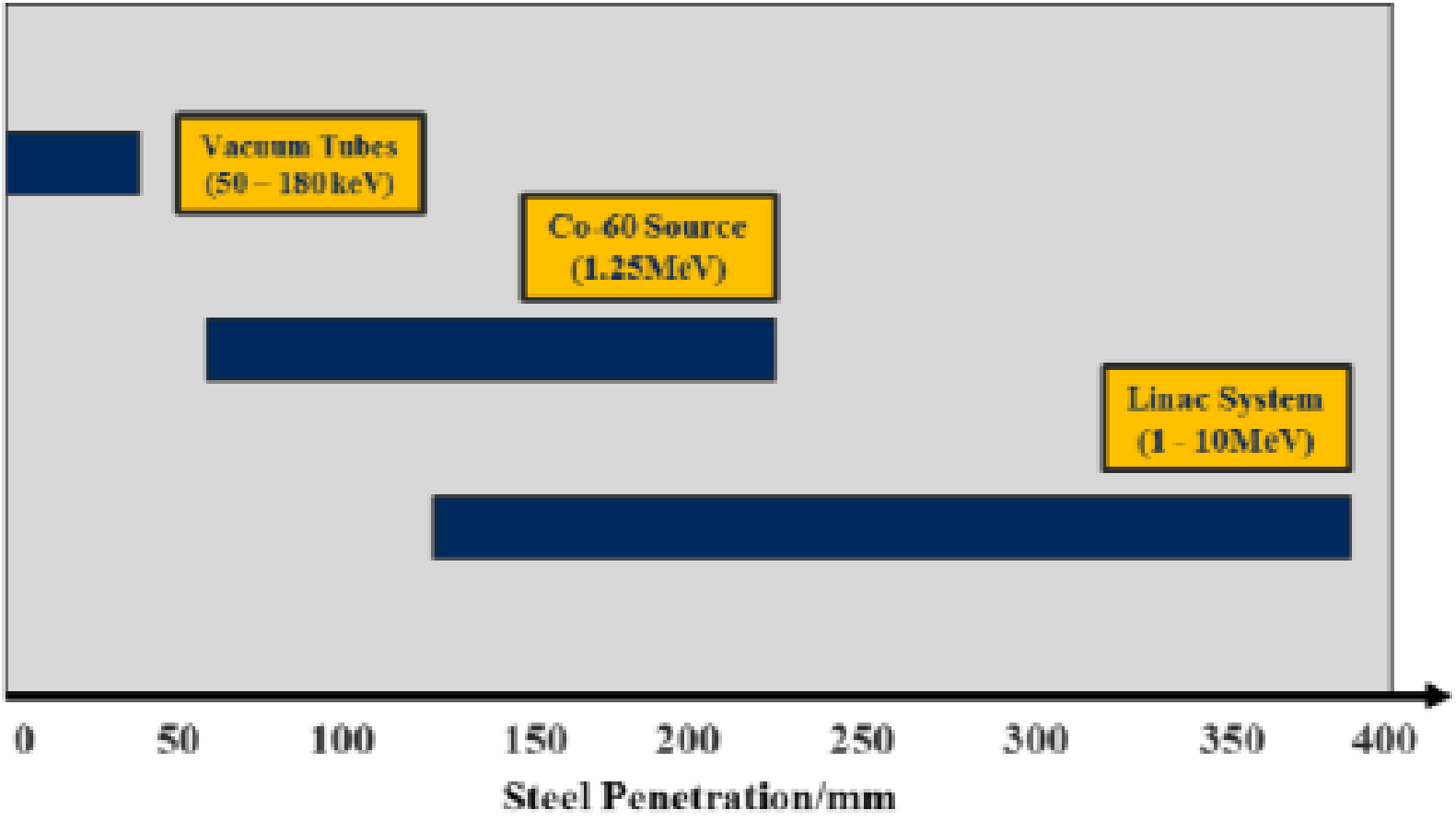
Image credited to Rapiscan.:Eagle M60

X-ray Sources
Variants [1]

Technology	Energy Range	Approximate Steel Penetration/mm	Method	Application	Limitations
Vacuum Tubes	50 - 450 keV	38	Electron beam acceleration and rapid deceleration by an anode target to create Bremsstrahlung	Baggage and mail scanning	Poor penetration so not suitable for CVI Above 150 keV there are anode cooling issues
Cobalt-60 Source	1.17-1.33 MeV [4]	63.5 - 229	Radioactive source emits gamma rays of different energies. The photopeaks for a scintillation counter occur at 1.17 and 1.33 MeV.	Vehicle inspection and non-destructive testing (NDT)	Source lifetime and output dose variation with half life
Linac Systems	2 - 10 MeV	133 - 390	Electron beam acceleration using a linear accelerator (linac) and absorption by a high-Z target to produce X-rays.	Heavy container and vehicle scanning	Above 6 MeV there is neutron production and more shielding required Poor penetration below 3 MeV

X-ray Sources

Electron Linacs are most often required for CVI



1) Security Screening Market

2) X-ray Sources

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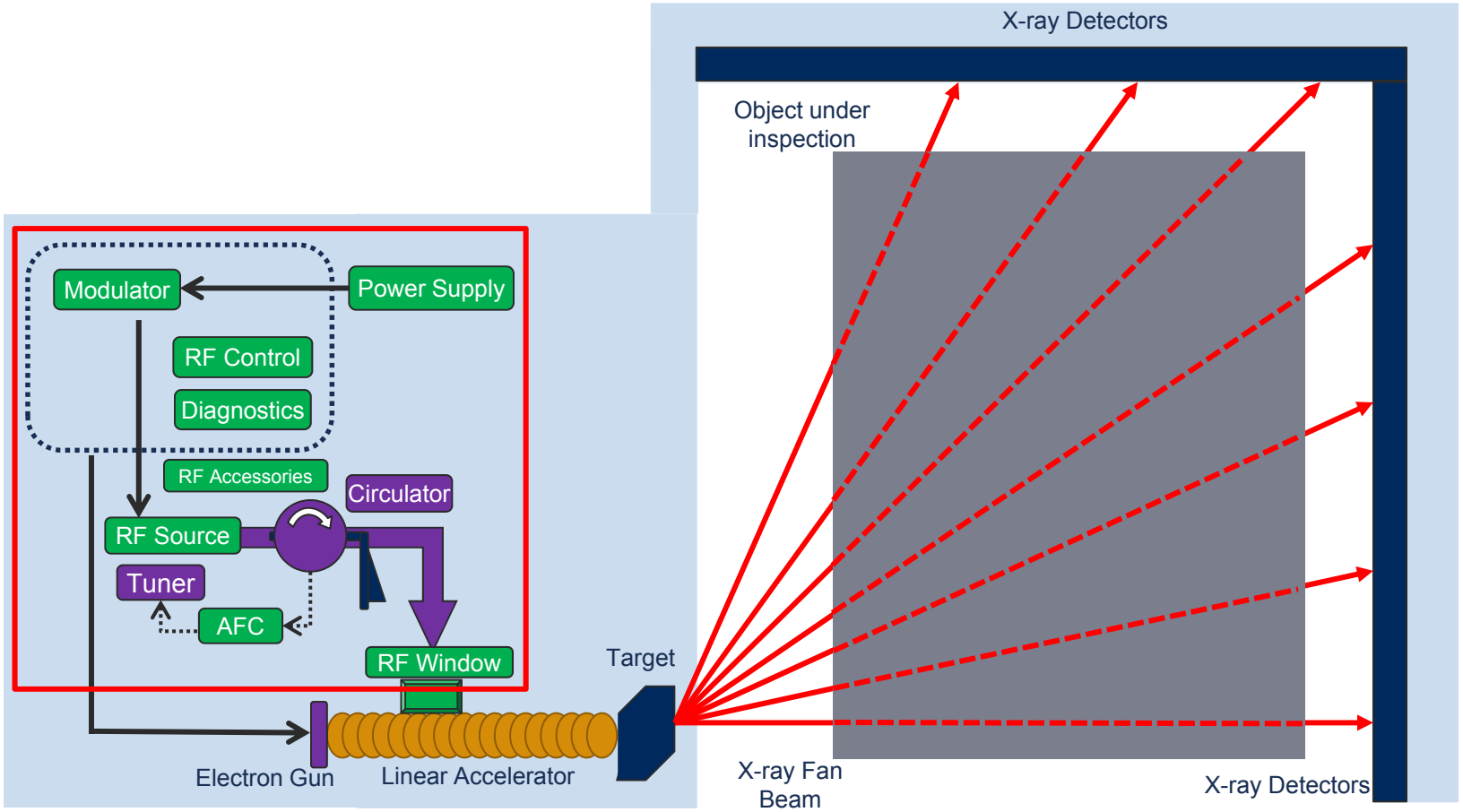
4) RF Sub-systems

5) Summary

X-ray Screening Systems

- Technology driven by user requirements for high throughput and accurate material identification. This is turn affects the RF sub-system and detector array.
- The X-ray screening systems in operation today currently using the following imaging techniques:
  - Transmission
  - Backscatter
  - Dual Energy
  - A combination of the above to improve material discrimination
- Transmission systems rely on the attenuation of X-ray photons as they pass through the object material. Denser materials appear brighter on positive contrast images, similar to X-ray imaging.
- Backscatter Systems can be used for luggage and personnel screening, and vehicle inspection. [9]
- Dual Energy Systems are used for CVI and border security applications.

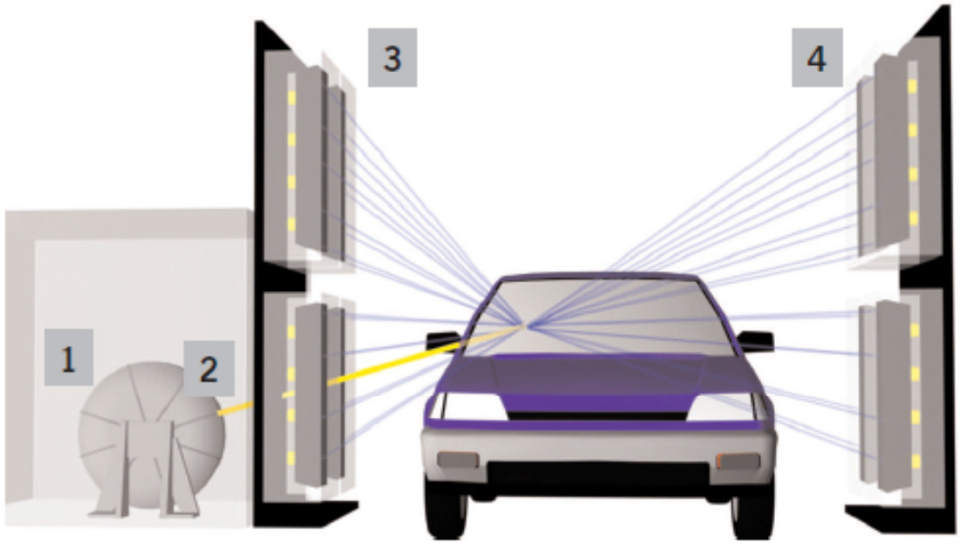
Linac X-ray Screening Systems
Transmission Systems



A schematic diagram to highlight the RF sub-system required for a typical fixed transmission linac screening system. The RF sub-system is highlighted by the components in the red box, items coloured green are currently offered by e2v and those in purple form future development work.

X-ray Screening Systems
Backscatter systems

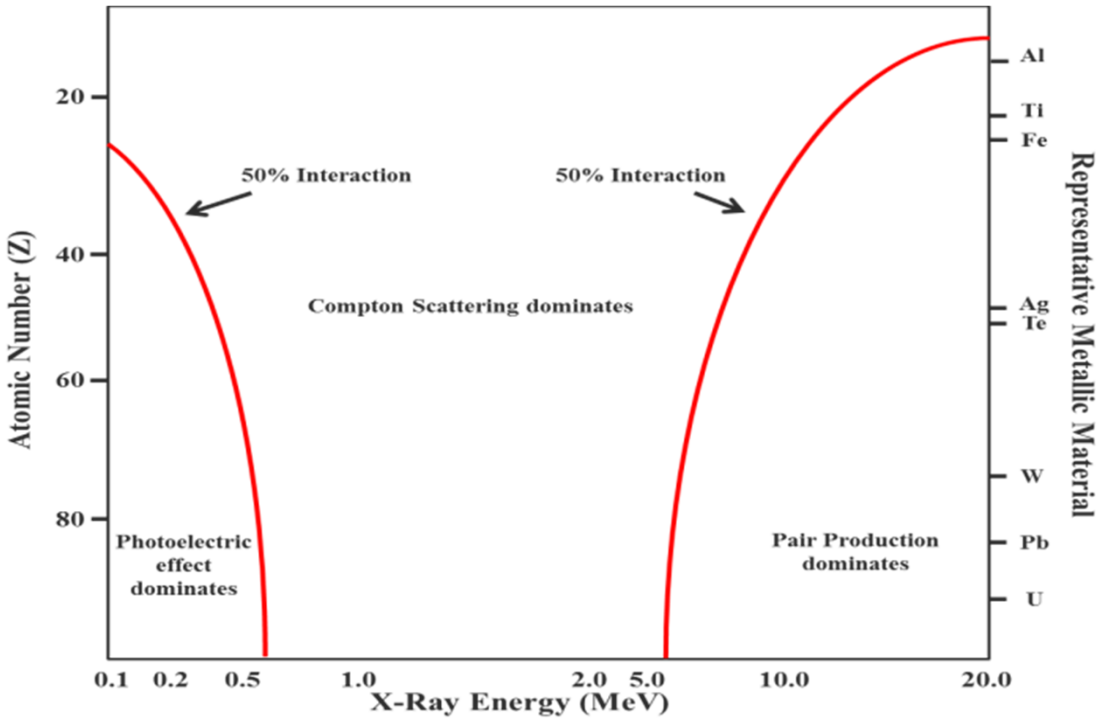
- X-ray source and large area detectors on the same side to detect Compton scattered photons
- Strong signal received from low-Z materials, but poor penetration of denser materials.



. Image credited to American Science and Engineering (AS&E) Inc.

X-ray Screening Systems
Dual Energy systems

- Linac used to interlace pulses of high and low X-ray energy for continuous imaging.
- Interaction mechanisms at different energies provided image contrast for organic and inorganic material.



1) Security Screening Market

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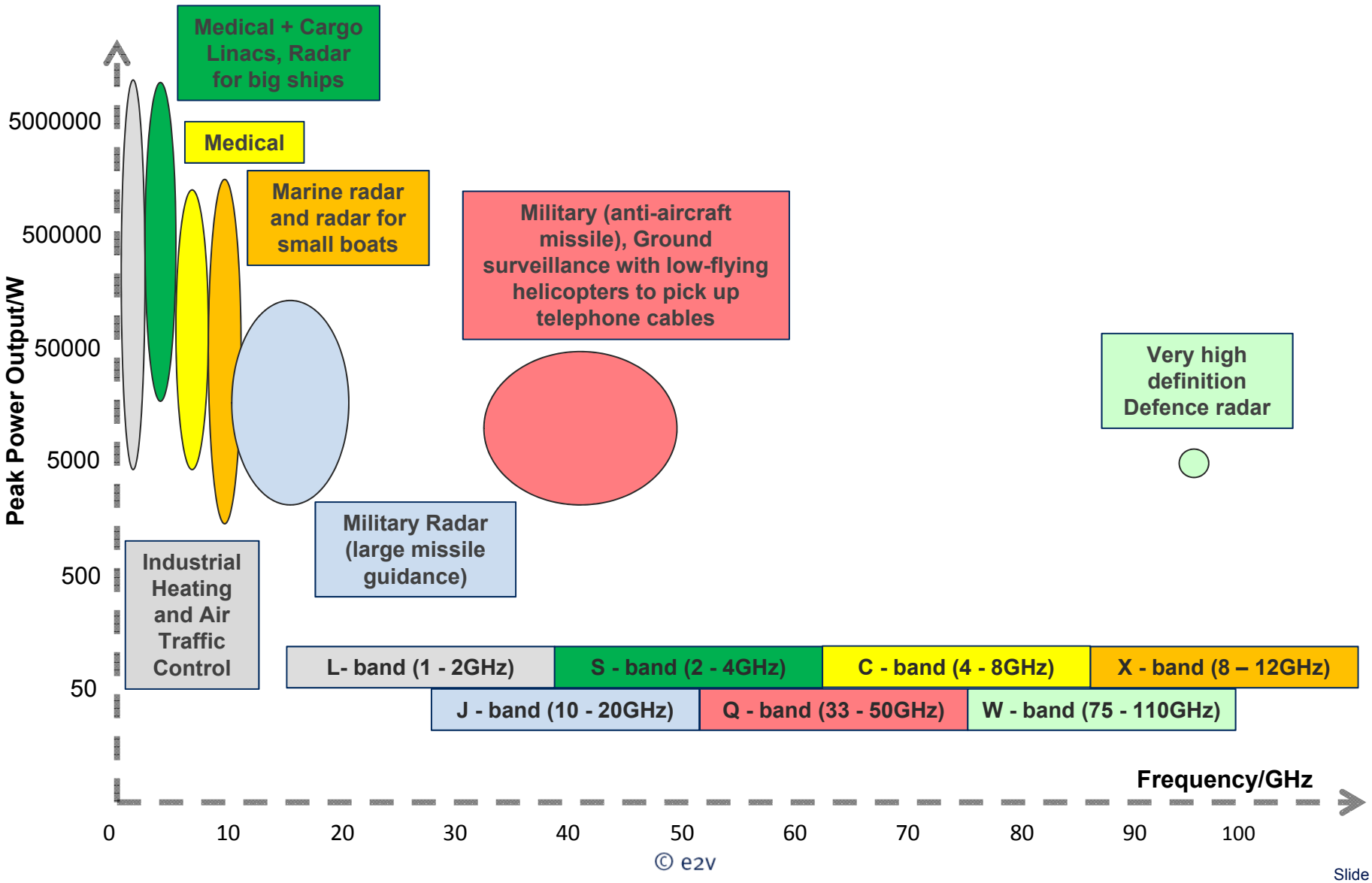
RF Technology
Introduction

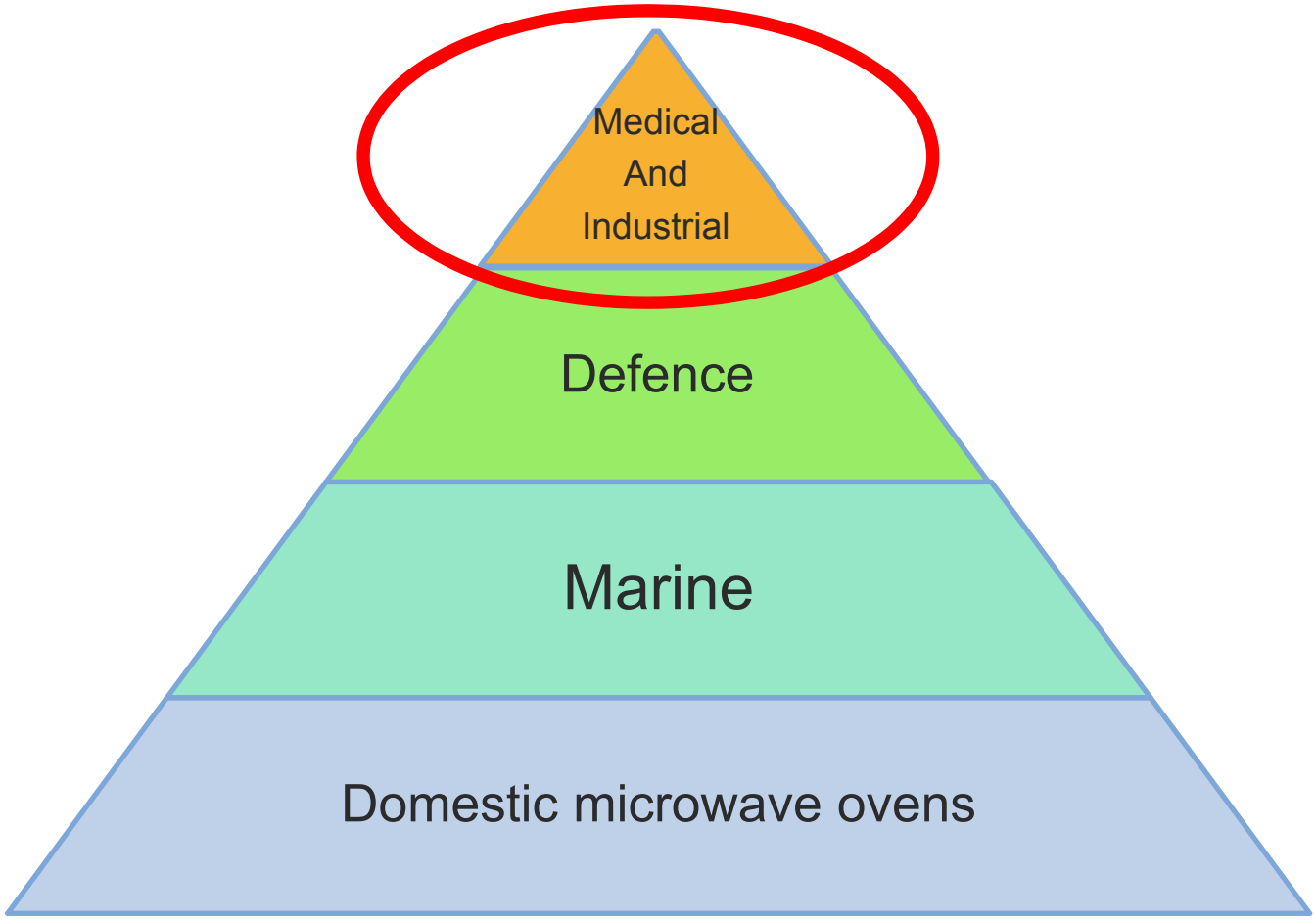
- The design skills required for RF power sub-systems in terms of specialised component design and manufacture mainly reside in companies.
- At present, some CVI system companies are demanding more integrated RF sub-systems.
- As such, e2v intends to not only drive the innovation in sources but provide sub-systems.

RF Technology

Typical magnetron source landscape and heritage



RF Technology
Global indicative annual volumes of Magnetrons



~ 4k

~20k

~ 150k

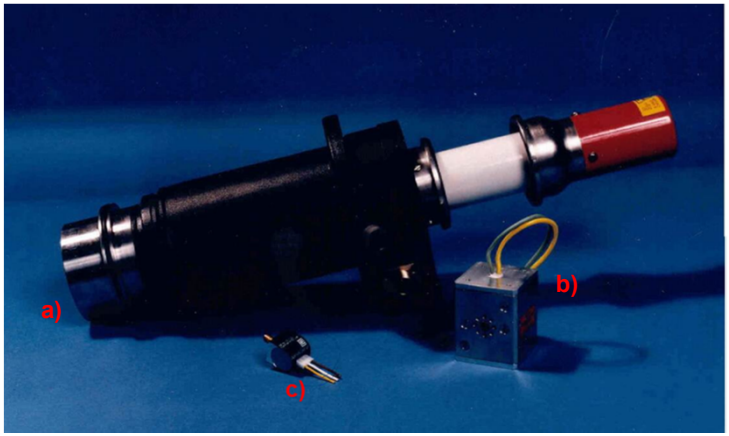
~ 150M

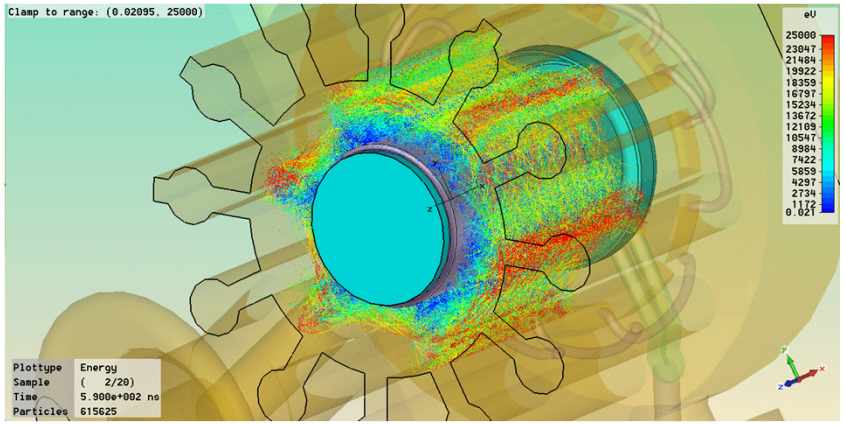
RF Technology
Magnetrons

- Magnetrons are efficient high peak power RF sources.

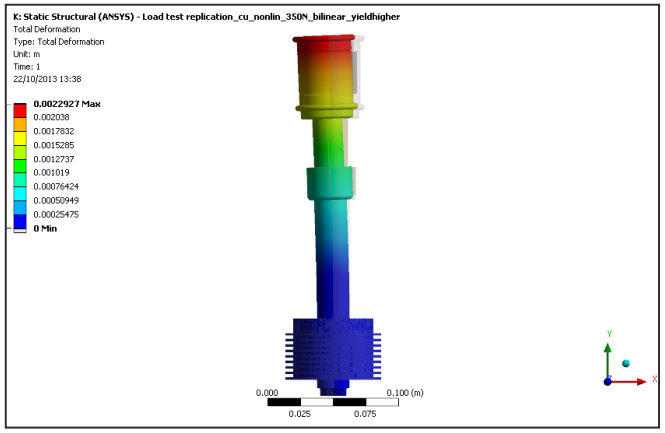
- Use a variety of anode designs for its magnetrons. These include:

1. Strap Vane
2. Long anode (L, S, C bands)
3. Coaxial (S, C, X, J, Q bands)
4. Rising Sun (J, Q, W bands)
5. Distributed Strap – an e2v patented design!

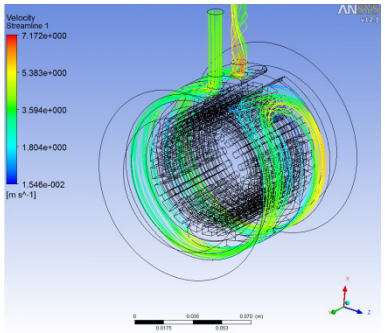


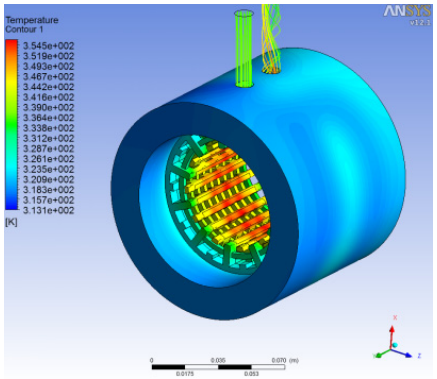


RF Technology
Extensive Magnetron Modelling

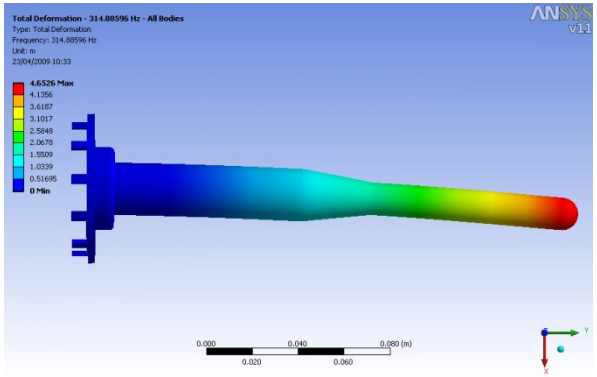


Sidearm structural modelling

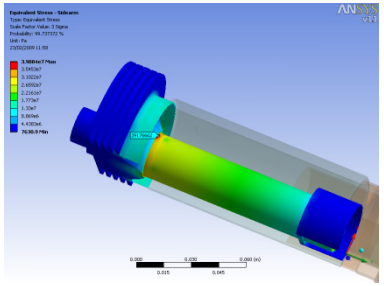


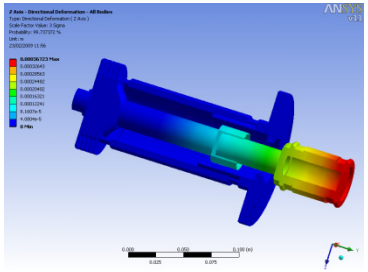


S-band anode cooling



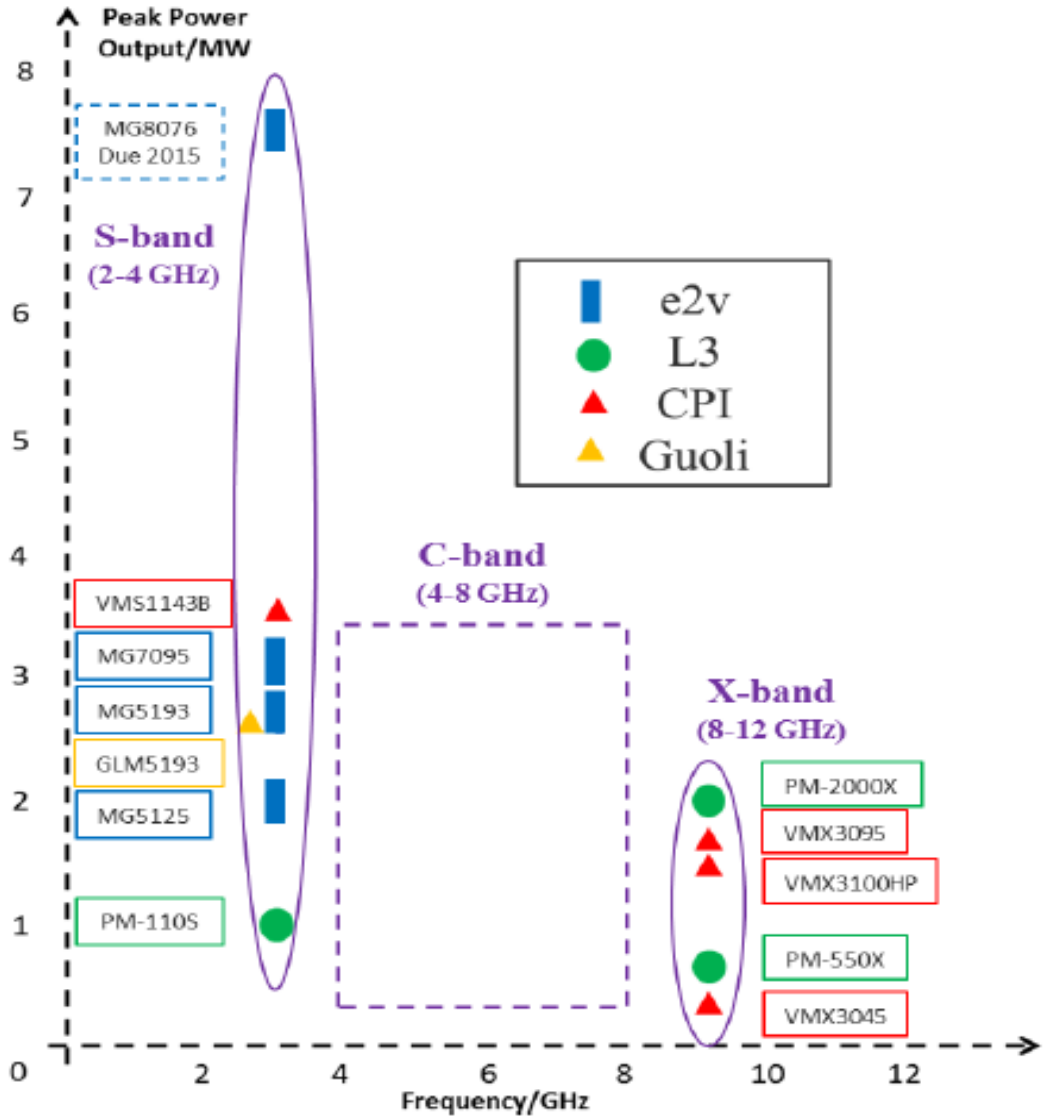
S-band output modal analysis





S-band sidearm transport random vibration

RF Technology
Magnetron Product used for CVI



Magnetrons for X-ray screening arranged for clarity [14, 15 & 16].

RF Technology
Magnetron Development

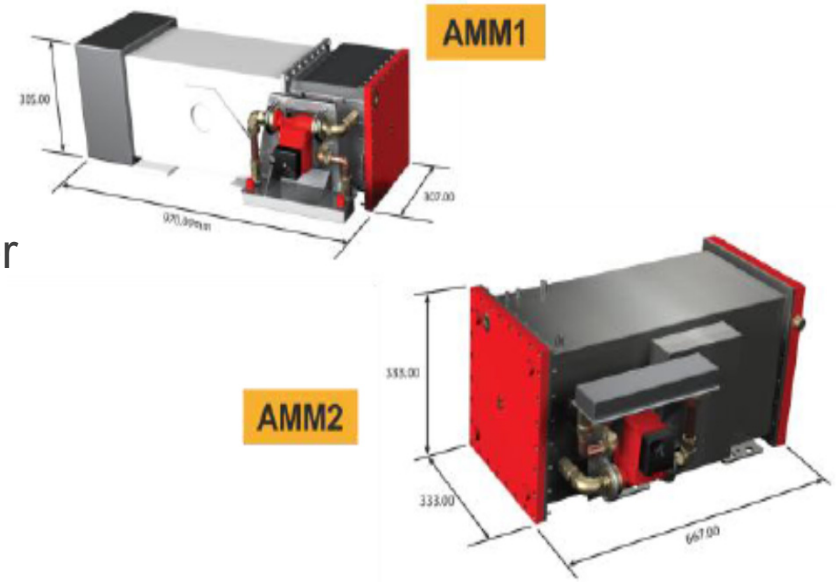
- A higher peak power - more penetration power
- High Average Power (AP) - yields a faster PRF or longer pulse widths.
- Missing RF pulses attributed to magnetron arcing cause lost slices in an image.
  - Arcs can appear in bursts – could require a re-scan.
  - As system requirements become less tolerant of arcing, e2v is developing efforts to reduce the arc rate by two orders of magnitude.

RF Technology
Modulators

- Produces a pulse to drive the magnetron. Current trend toward solid state modulators as opposed to the older line-type devices due to size – as compact RF sub-systems are more desirable.

- e2v currently offer the AMM1 solid state modulator (>600 units fielded)

- AMM2 provides a number of benefits over its predecessor in terms of:
  - Smaller and lighter design
  - Field replaceable units and remote diagnostics
  - An improved pulse shaping - which improves magnetron starting performance.
  - Improved efficiency

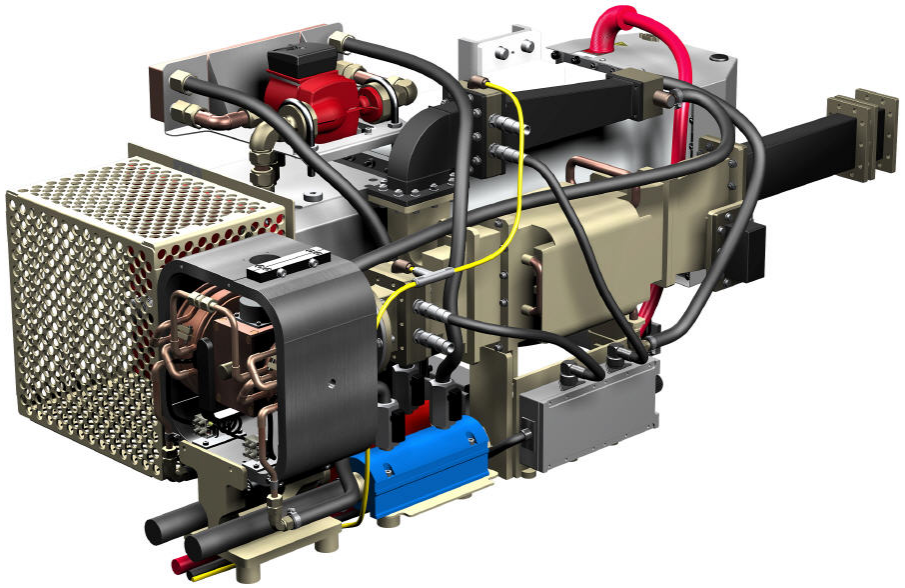


RF Technology
RF Sub-System Development

- Future development for e2v building on our RF component technology.

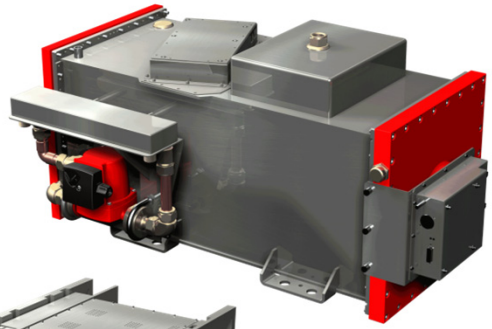
- This will provide benefits to the user and system manufacturer in terms of:

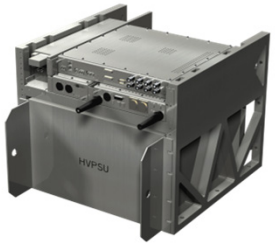
  - Optimised Interfaces
  - Component and system compatibility
  - Integrated diagnostics
  - Fault reporting
  - Scheduled maintenance and service requests



RF Technology

e2v's Linac Security Screening Portfolio



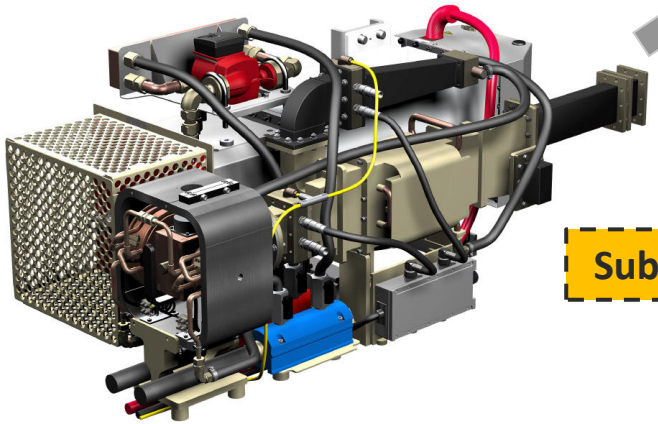


Modulators

Magnetrons

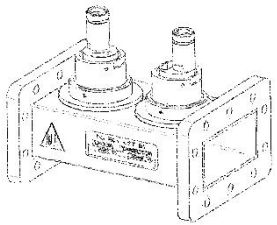
Thyratrons

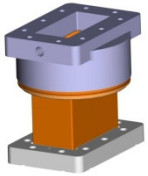
X-ray Security Applications

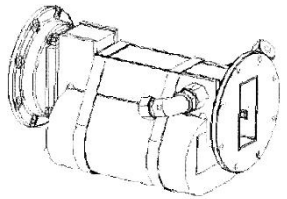


Sub-systems

RF Accessories







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5) Summary

Summary

- Linac based X-ray sources are the usual choice for CVI applications – because they can produce the required penetration
- Development of RF sub-systems for linac screening applications has led to higher throughput and improved material discrimination – driven by user requirements.
- Demand for linacs will be driven primarily by cargo screening and border protection needs. Slated to grow at c. 7% CAGR (however this business is heavily influenced by governmental policies on homeland security, political change and government budgets etc.)
- Future systems will need to offer faster throughput with less false positives and improved material discrimination to compete in the market.
- e2v supplies is committed to the continued supply and development of RF equipment for CVI (magnetrons, thyratrons, solid-state modulators and passive waveguide components) and can offer microwave subsystems too.

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Questions ?