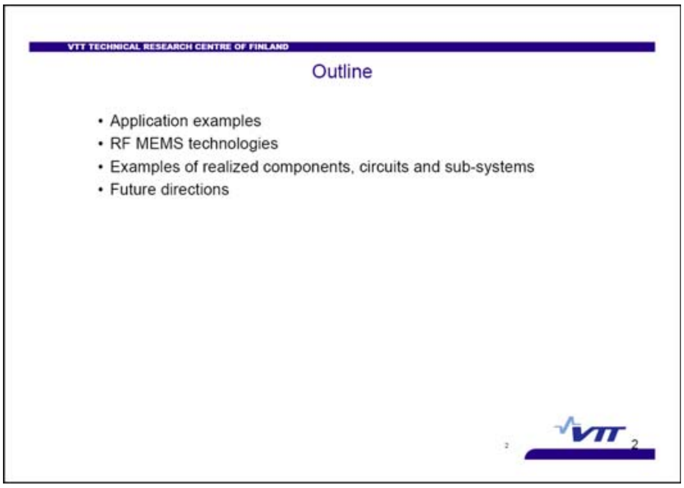
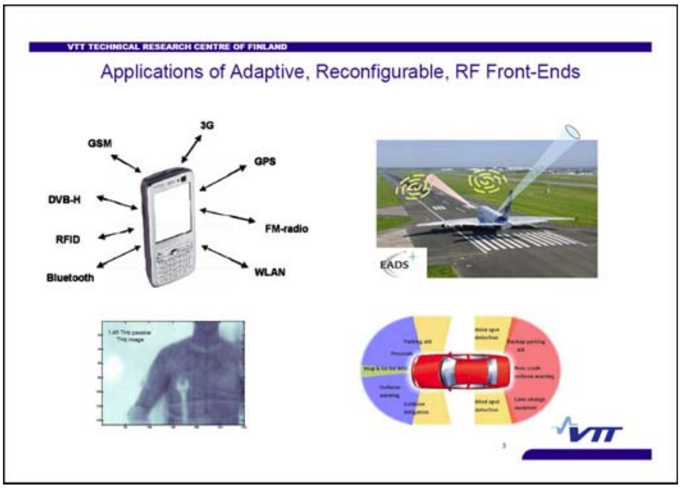
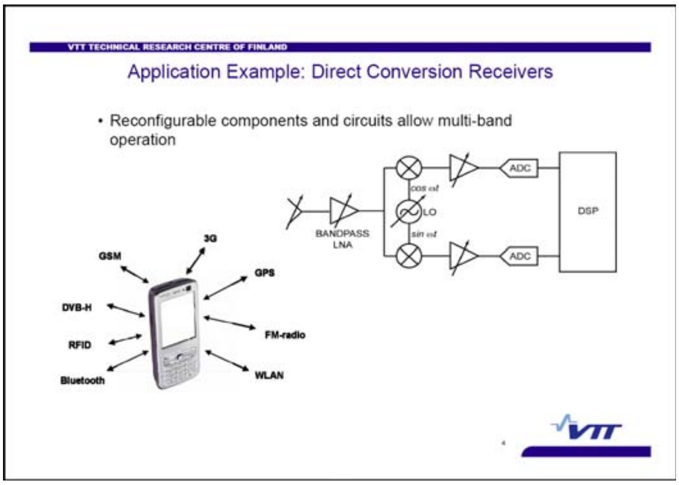
RECONFIGURABLE RF MEMS CIRCUITS

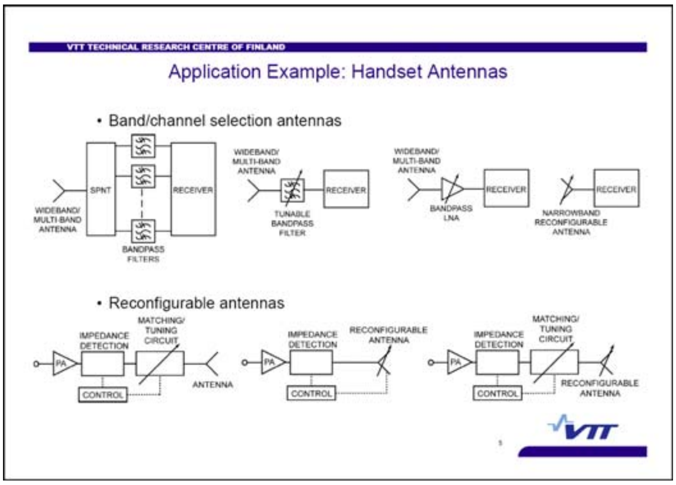
Tauno Vähä-Heikkilä

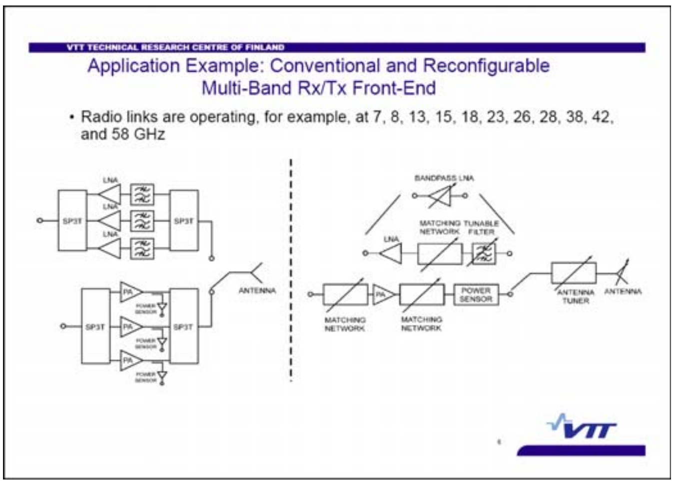
MilliLab, VTT Technical Research Centre of Finland Espoo, Finland

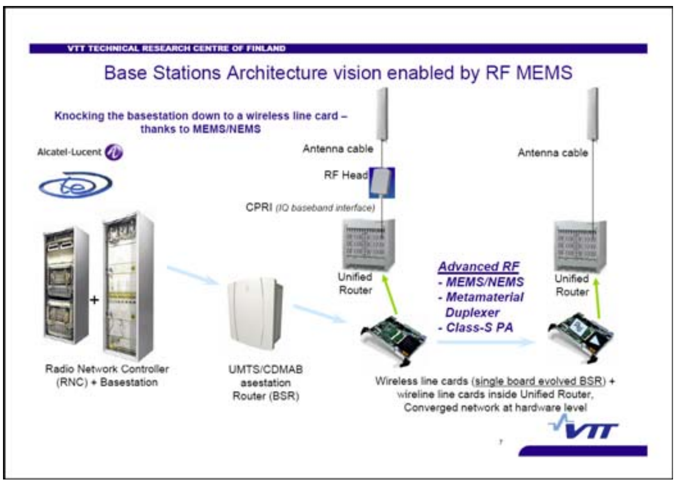


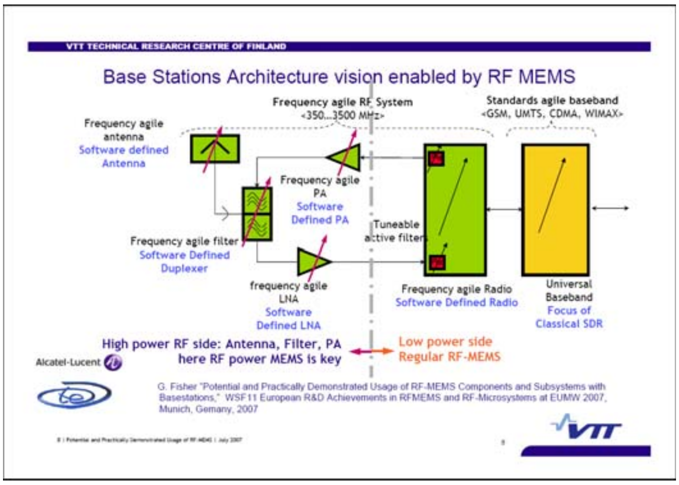


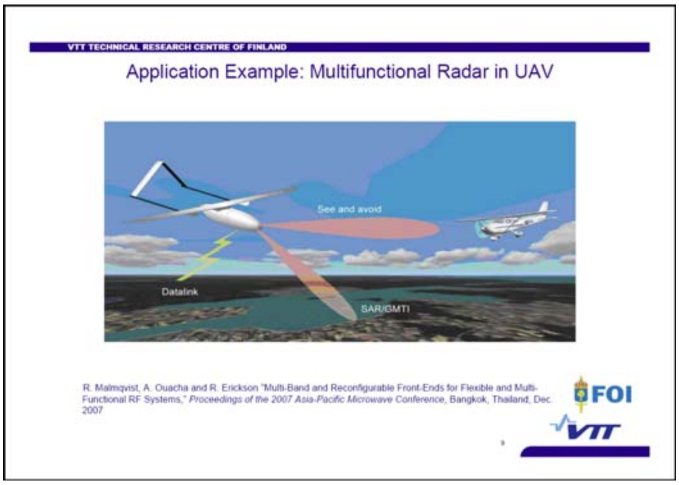




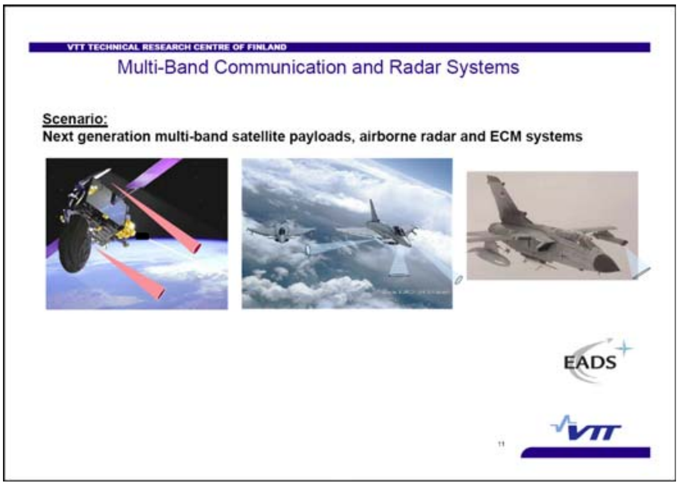


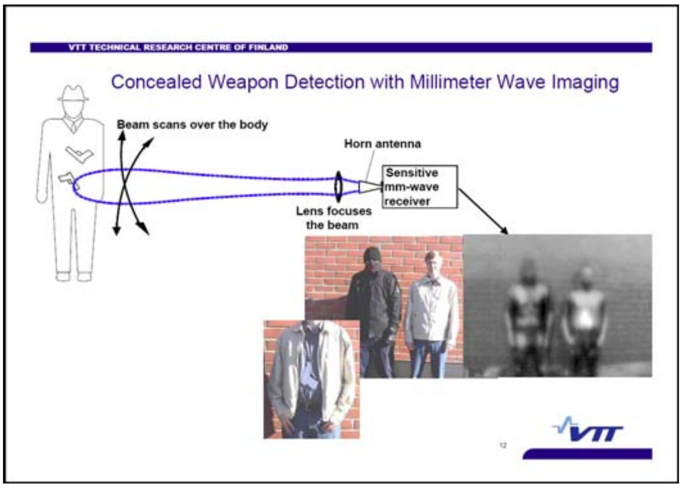


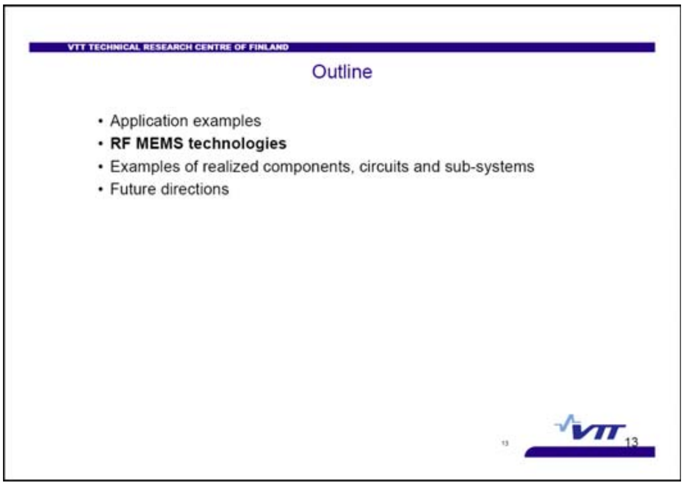

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Base Stations Architecture vision enabled by RF MEMS
Frequency agile antenna
Software defined Antenna
Frequency agile RF System
<350...3500 MHz>
Standards agile baseband
<GSM, UMTS, CDMA, WIMAX>
Frequency agile PA
Software Defined PA
Tuneable active filter
Frequency agile filter
Software Defined Duplexer
frequency agile LNA
Software Defined LNA
Frequency agile Radio
Software Defined Radio
Universal Baseband
Focus of Classical SDR
High power RF side: Antenna, Filter, PA
here RF power MEMS is key
Low power side
Regular RF-MEMS
Alcatel-Lucent
G. Fisher "Potential and Practically Demonstrated Usage of RF-MEMS Components and Subsystems with Basestations," WSF11 European R&D Achievements in RFMEMS and RF-Microsystems at EUMW 2007, Munich, Gemany, 2007
VTT

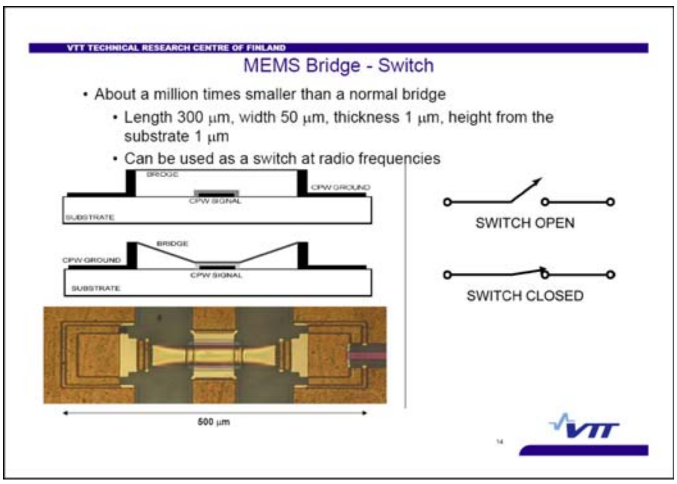

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Application Example: Multifunctional Radar in UAV
See and avoid
Datalink
SAR/GMTI
R. Malmqvist, A. Ouacha and R. Erickson "Multi-Band and Reconfigurable Front-Ends for Flexible and Multi-Functional RF Systems," Proceedings of the 2007 Asia-Pacific Microwave Conference, Bangkok, Thailand, Dec 2007
FOI
VTT

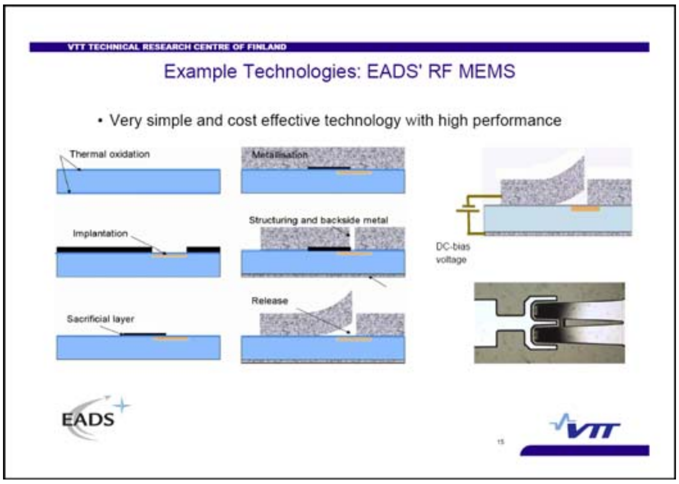

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Electronically Steerable Antennas: for Communication
Scenario:
Bi-directional broadband SatCom links from a mobile platform to a satellite and vice-versa.
EADS
VTT

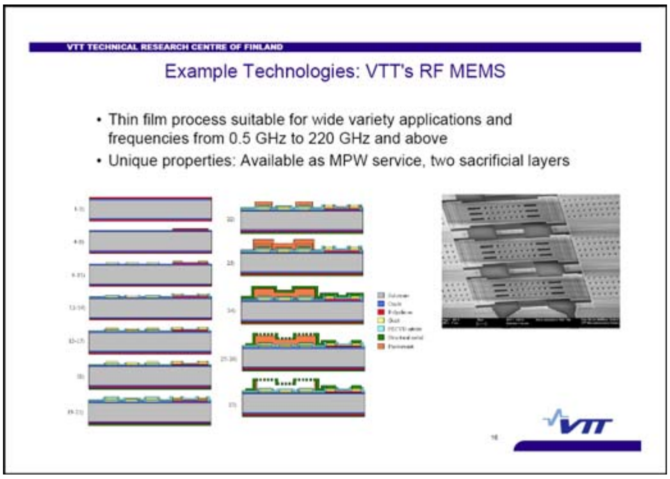

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Multi-Band Communication and Radar Systems
Scenario:
Next generation multi-band satellite payloads, airborne radar and ECM systems
EADS
VTT

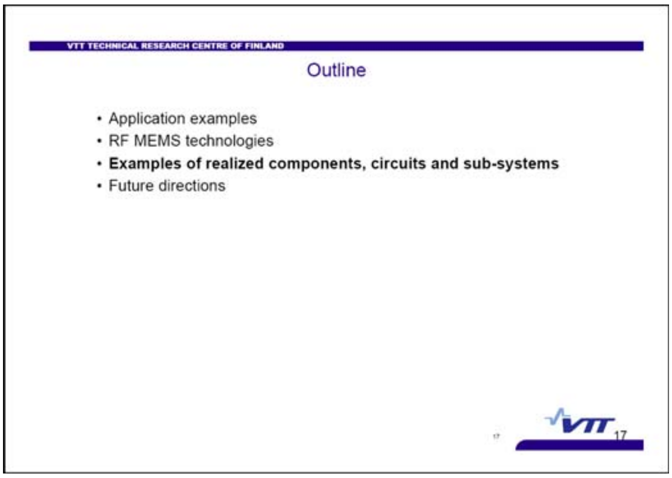

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Concealed Weapon Detection with Millimeter Wave Imaging
Beam scans over the body
Horn antenna
Sensitive mm-wave receiver
Lens focuses the beam
VTT

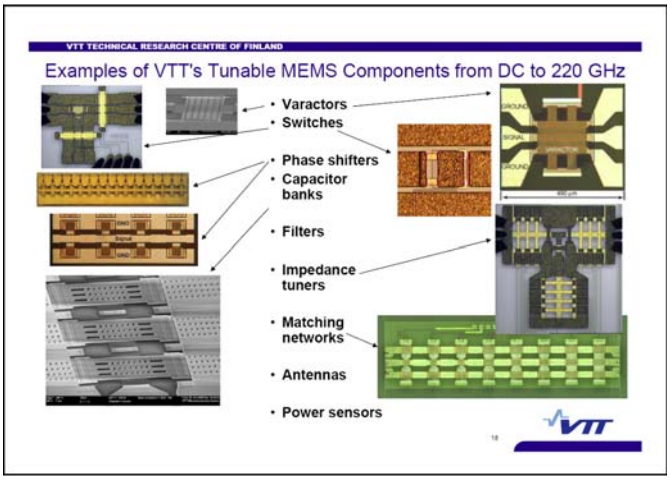

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Outline
• Application examples
• RF MEMS technologies
• Examples of realized components, circuits and sub-systems
• Future directions
VTT
13

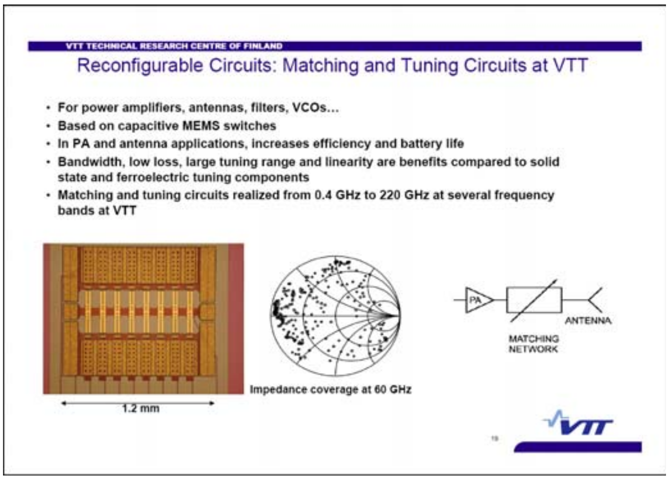

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
MEMS Bridge - Switch
• About a million times smaller than a normal bridge
• Length 300 μm, width 50 μm, thickness 1 μm, height from the substrate 1 μm
• Can be used as a switch at radio frequencies
BRIDGE
CPW GROUND
CPW SIGNAL
SUBSTRATE
SWITCH OPEN
SWITCH CLOSED
500 μm
VTT

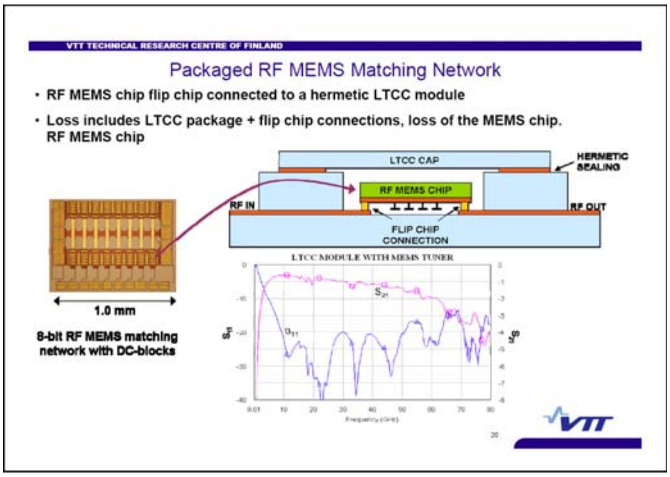

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Example Technologies: EADS' RF MEMS
• Very simple and cost effective technology with high performance
Thermal oxidation
Metallisation
Implantation
Structuring and backside metal
Sacrificial layer
Release
DC-bias voltage
EADS
VTT

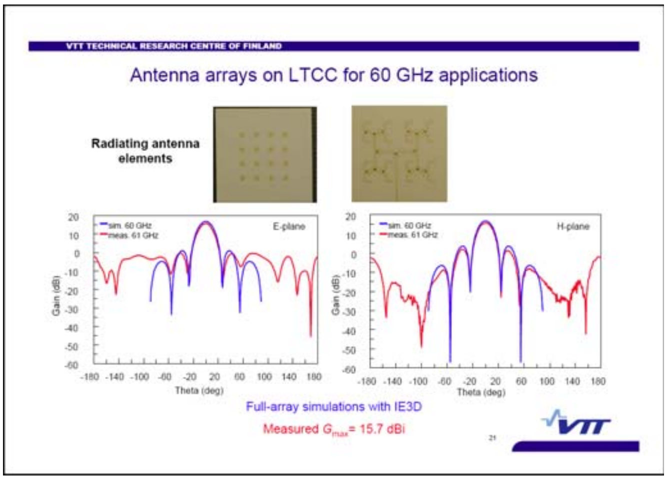

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Example Technologies: VTT's RF MEMS
• Thin film process suitable for wide variety applications and frequencies from 0.5 GHz to 220 GHz and above
• Unique properties: Available as MPW service, two sacrificial layers
VTT

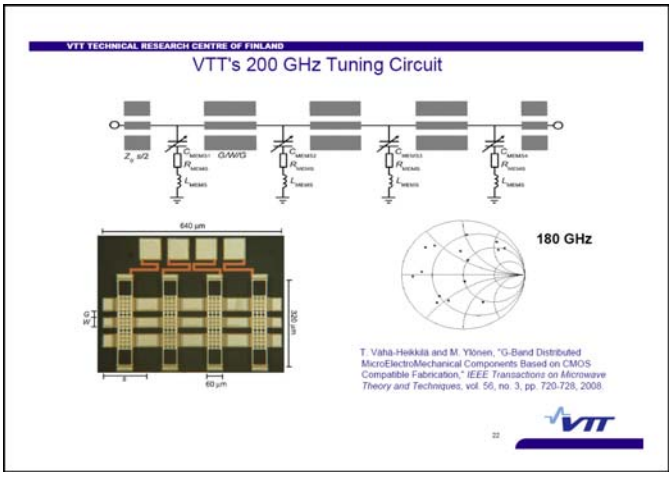

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Outline
• Application examples
• RF MEMS technologies
• Examples of realized components, circuits and sub-systems
• Future directions
VTT
17

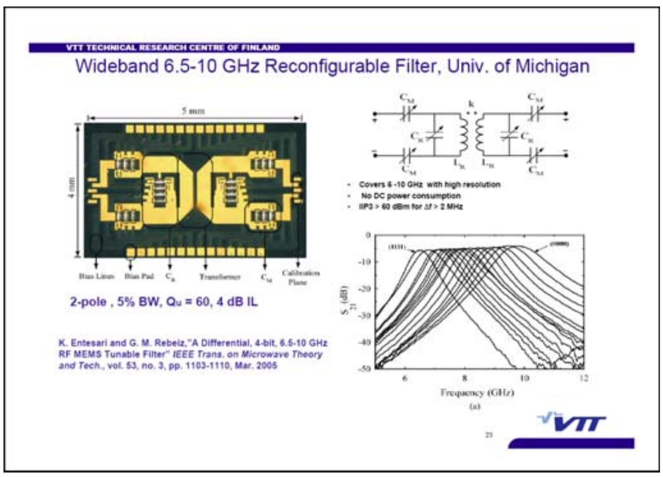

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Examples of VTT's Tunable MEMS Components from DC to 220 GHz
• Varactors
• Switches
• Phase shifters
• Capacitor banks
• Filters
• Impedance tuners
• Matching networks
• Antennas
• Power sensors
VTT

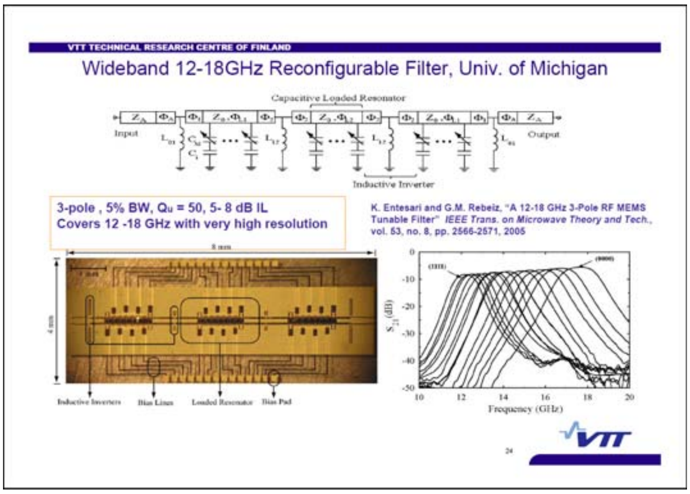

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Reconfigurable Circuits: Matching and Tuning Circuits at VTT
• For power amplifiers, antennas, filters, VCOs...
• Based on capacitive MEMS switches
• In PA and antenna applications, increases efficiency and battery life
• Bandwidth, low loss, large tuning range and linearity are benefits compared to solid state and ferroelectric tuning components
• Matching and tuning circuits realized from 0.4 GHz to 220 GHz at several frequency bands at VTT
1.2 mm
Impedance coverage at 60 GHz
PA
ANTENNA
MATCHING NETWORK
VTT

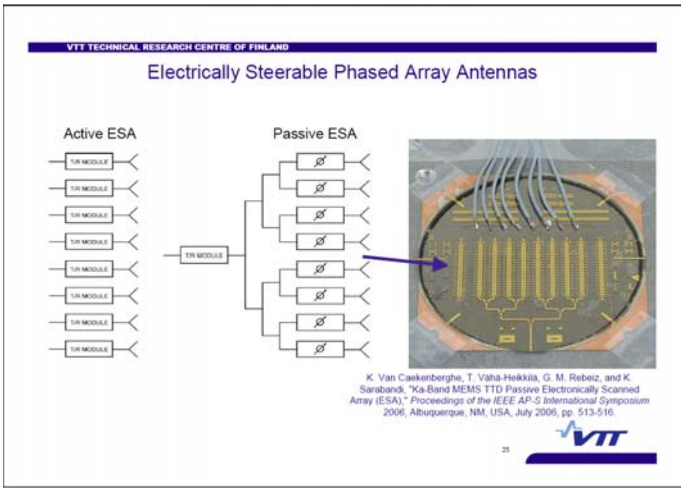

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Packaged RF MEMS Matching Network
• RF MEMS chip flip chip connected to a hermetic LTCC module
• Loss includes LTCC package + flip chip connections, loss of the MEMS chip. RF MEMS chip
LTCC CAP
HERMETIC SEALING
RF MEMS CHIP
RF IN
RF OUT
FLIP CHIP CONNECTION
LTCC MODULE WITH MEMS TUNER
1.0 mm
8-bit RF MEMS matching network with DC-blocks
VTT

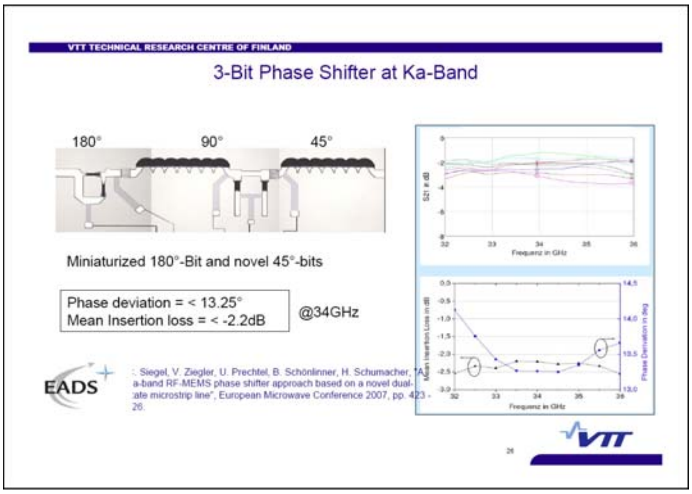

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Antenna arrays on LTCC for 60 GHz applications
Radiating antenna elements
sim. 60 GHz
meas. 61 GHz
E-plane
H-plane
Gain (dB)
Theta (deg)
Full-array simulations with IE3D
Measured G_{max} = 15.7 dBi
VTT

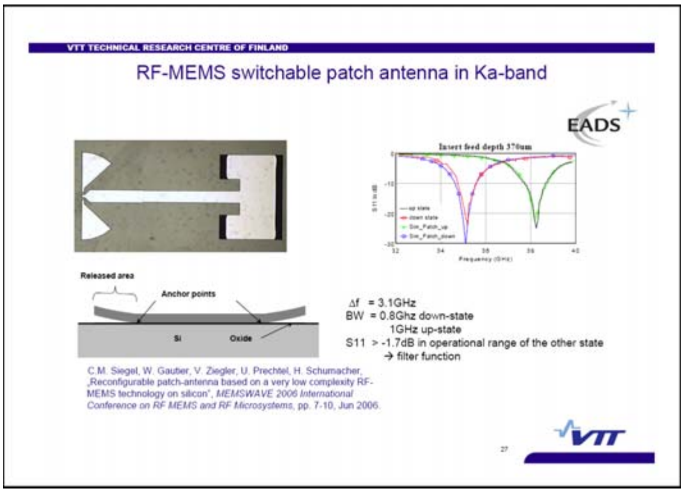

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
VTT's 200 GHz Tuning Circuit
640 µm
320 µm
180 GHz
T. Vähä-Heikkilä and M. Ylönen, "G-Band Distributed MicroElectroMechanical Components Based on CMOS Compatible Fabrication," IEEE Transactions on Microwave Theory and Techniques, vol. 56, no. 3, pp. 720-728, 2008.
VTT

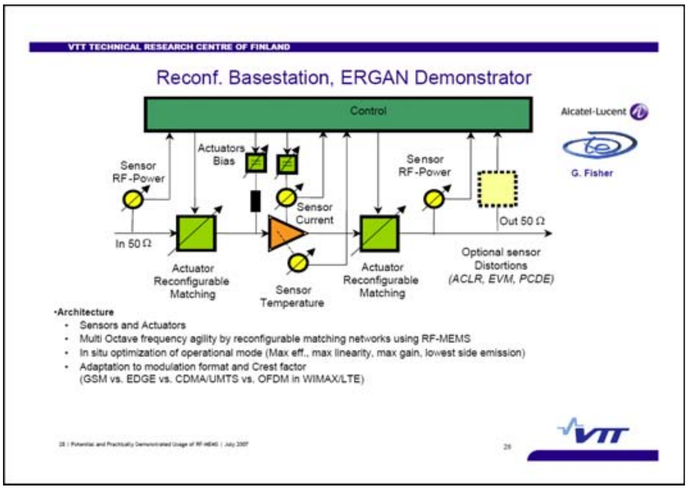

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Wideband 6.5-10 GHz Reconfigurable Filter, Univ. of Michigan
5 mm
4 mm
• Covers 6 -10 GHz with high resolution
• No DC power consumption
• IIP3 > 60 dBm for Δf > 2 MHz
2-pole , 5% BW, Qu = 60, 4 dB IL
K. Entesari and G. M. Rebeiz,"A Differential, 4-bit, 6.5-10 GHz RF MEMS Tunable Filter" IEEE Trans. on Microwave Theory and Tech., vol. 53, no. 3, pp. 1103-1110, Mar. 2005
Frequency (GHz)
VTT

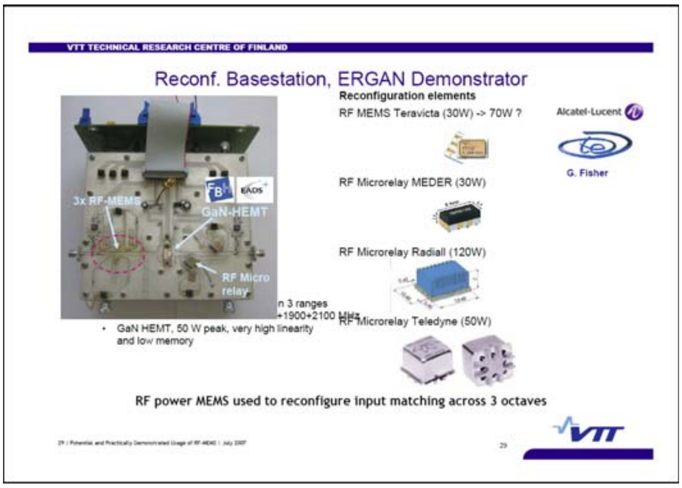

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Wideband 12-18GHz Reconfigurable Filter, Univ. of Michigan
Capacitive Loaded Resonator
Input
Output
Inductive Inverter
3-pole , 5% BW, Qu = 50, 5- 8 dB IL
Covers 12 -18 GHz with very high resolution
K. Entesari and G.M. Rebeiz, "A 12-18 GHz 3-Pole RF MEMS Tunable Filter" IEEE Trans. on Microwave Theory and Tech., vol. 53, no. 8, pp. 2566-2571, 2005
Inductive Inverters
Bias Lines
Loaded Resonator
Bias Pad
Frequency (GHz)
24
VTT


VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Electrically Steerable Phased Array Antennas
Active ESA
Passive ESA
T/R MODULE
K. Van Caekenberghe, T. Vähä-Heikkilä, G. M. Rebeiz, and K. Sarabandi, "Ka-Band MEMS TTD Passive Electronically Scanned Array (ESA)," Proceedings of the IEEE AP-S International Symposium 2006, Albuquerque, NM, USA, July 2006, pp. 513-516.
25
VTT


VTT TECHNICAL RESEARCH CENTRE OF FINLAND
3-Bit Phase Shifter at Ka-Band
180°
90°
45°
Miniaturized 180°-Bit and novel 45°-bits
Phase deviation = < 13.25°
Mean Insertion loss = < -2.2dB
@34GHz
EADS
Frequenz in GHz
26
VTT


VTT TECHNICAL RESEARCH CENTRE OF FINLAND
RF-MEMS switchable patch antenna in Ka-band
EADS
Released area
Anchor points
Si
Oxide
Δf = 3.1GHz
BW = 0.8Ghz down-state
1GHz up-state
S11 > -1.7dB in operational range of the other state
→ filter function
C.M. Siegel, W. Gautier, V. Ziegler, U. Prechtel, H. Schumacher, „Reconfigurable patch-antenna based on a very low complexity RF-MEMS technology on silicon", MEMSWAVE 2006 International Conference on RF MEMS and RF Microsystems, pp. 7-10, Jun 2006.
27
VTT


VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Reconf. Basestation, ERGAN Demonstrator
Control
Alcatel-Lucent
G. Fisher
Sensor RF-Power
Actuators Bias
Sensor Current
Sensor RF-Power
In 50 Ω
Out 50 Ω
Actuator Reconfigurable Matching
Sensor Temperature
Actuator Reconfigurable Matching
Optional sensor Distortions (ACLR, EVM, PCDE)
•Architecture
Sensors and Actuators
Multi Octave frequency agility by reconfigurable matching networks using RF-MEMS
In situ optimization of operational mode (Max eff., max linearity, max gain, lowest side emission)
Adaptation to modulation format and Crest factor
(GSM vs. EDGE vs. CDMA/UMTS vs. OFDM in WIMAX/LTE)
28
VTT

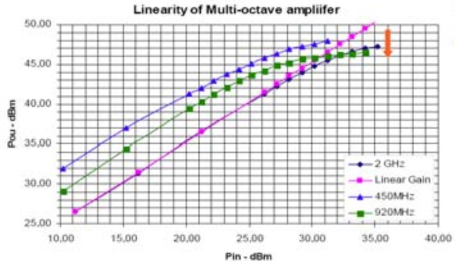

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Reconf. Basestation, ERGAN Demonstrator
Reconfiguration elements
RF MEMS Teravicta (30W) -> 70W ?
Alcatel-Lucent
G. Fisher
3x RF-MEMS
GaN-HEMT
RF Micro relay
RF Microrelay MEDER (30W)
RF Microrelay Radiall (120W)
RF Microrelay Teledyne (50W)
GaN HEMT, 50 W peak, very high linearity and low memory
RF power MEMS used to reconfigure input matching across 3 octaves
29
VTT

VTT TECHNICAL RESEARCH CENTRE OF FINLAND

Reconf. Basestation, ERGAN Demonstrator

Switching between 3 different frequency ranges

Linearity of Multi-octave ampliifer



Alcatel-Lucent

G. Fisher "Potential and Practically Demonstrated Usage of RF-MEMS Components and Subsystems with Basestations," WSF11 European R&D Achievements in RFMEMS and RF-Microsystems at EUMW 2007, Munich, Gemany, 2007

30

VTT

VTT TECHNICAL RESEARCH CENTRE OF FINLAND

Technologies Available for Everybody RF-PLATFORM MPW Run Schedule

- **LTCC**
  - Deadline for designs: Jan. 28th 2009. Technology provider: VIA electronic
- **SiGe2RF**
  - Deadline for designs: Dec. 15th 2008. Technology provider: ATMEL
- **RF MEMS - 1**
  - Deadline for designs: Dec. 18th 2008. Technology provider: Fraunhofer ISIT
- **RF MEMS - 2**
  - Deadline for designs: Dec. 12th 2008. Technology provider: THALES
- **IPD** (Integrated Passive Devices) -1 copper layer
  - Deadline for designs: Jan. 16th 2009. Technology provider: VTT
- **IPD** -2 copper layers
  - Deadline for designs: Oct 31st 2008. Technology provider: VTT

RF PLATFORM

31

VTT

VTT TECHNICAL RESEARCH CENTRE OF FINLAND

Outline

- Application examples
- RF MEMS technologies
- Examples of realized components, circuits and sub-systems
- **Future directions**

32

VTT 32

VTT TECHNICAL RESEARCH CENTRE OF FINLAND

Future Directions (1)

- Passive concepts
  - Passive elements such as antennas, feed networks, matching circuits are fabricated to low loss substrates with RF MEMS switches and circuits
  - Sub-system example: passive electrically steerable array
- Heterogeneous integration
  - Active and RF MEMS components are stacked and connected with cost effective interconnection and wafer level techniques
  - Can be very cost and size effective

33

VTT

VTT TECHNICAL RESEARCH CENTRE OF FINLAND

Future Directions

- Monolithic integration
  - RFIC/MMIC are integrated together with RF MEMS switches and circuits
  - Maximizes the integration level at the same chip
  - Lower number of interconnects
  - On-going EU-funded project MEMS-4-MMIC

MEMS 4 MMIC

VTT OMMIC FOI SAAB

34

VTT