MicroSTAR
A Bistatic radar solution to commoditise SAR

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CSIR

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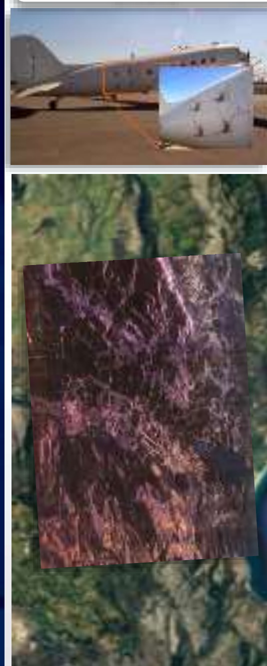
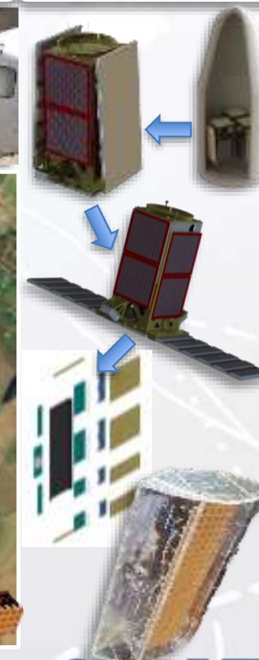
SAR History at CSIR and current developments

VHF SAR (1999)	L-band SAR (2007)	C/L band SAR Facility (2015 onwards)	UAV SAR MVP (2019 onwards)	Spaceborne SAR (2018 onwards)





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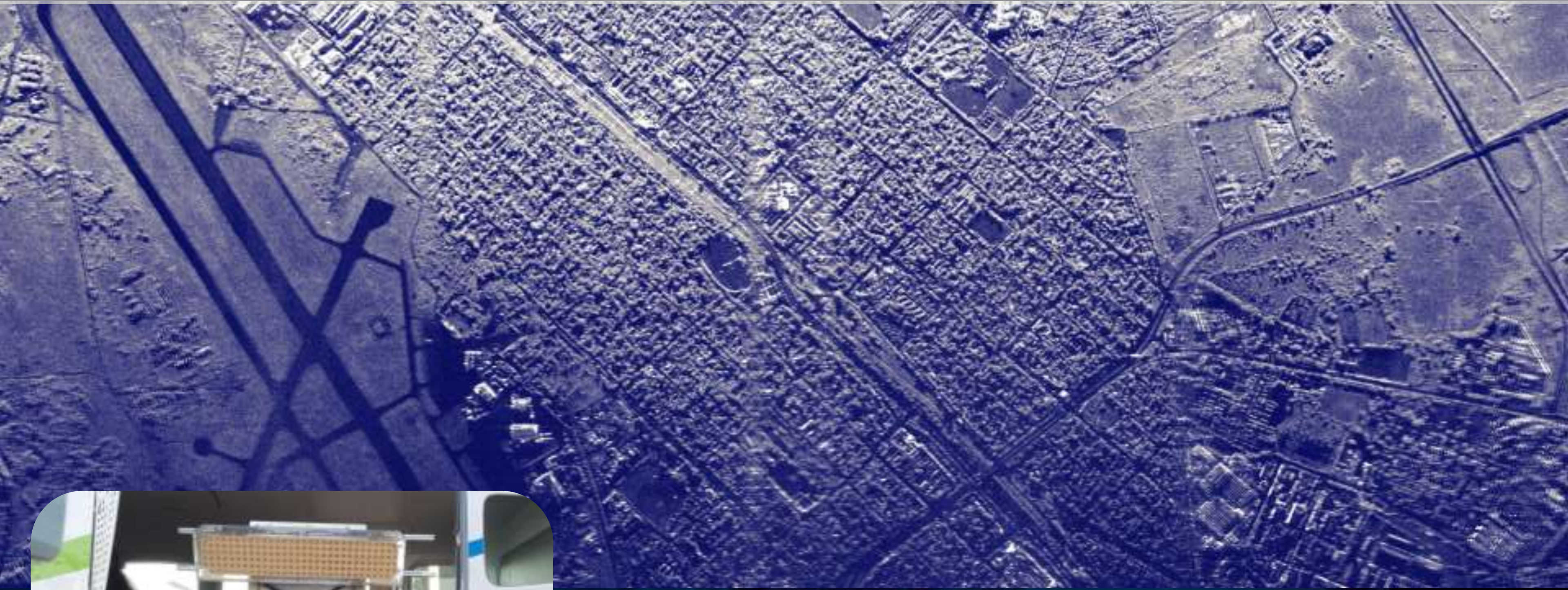
Synthetic Aperture Radar: Making sense of our world through clouds, at night – even through trees



SAR Image produced by
CSIR Airborne SAR facility

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Synthetic Aperture Radar: Making sense of our world through clouds, at night – even through trees

ICEYE

Long Dwell Image
produced by ICEYE

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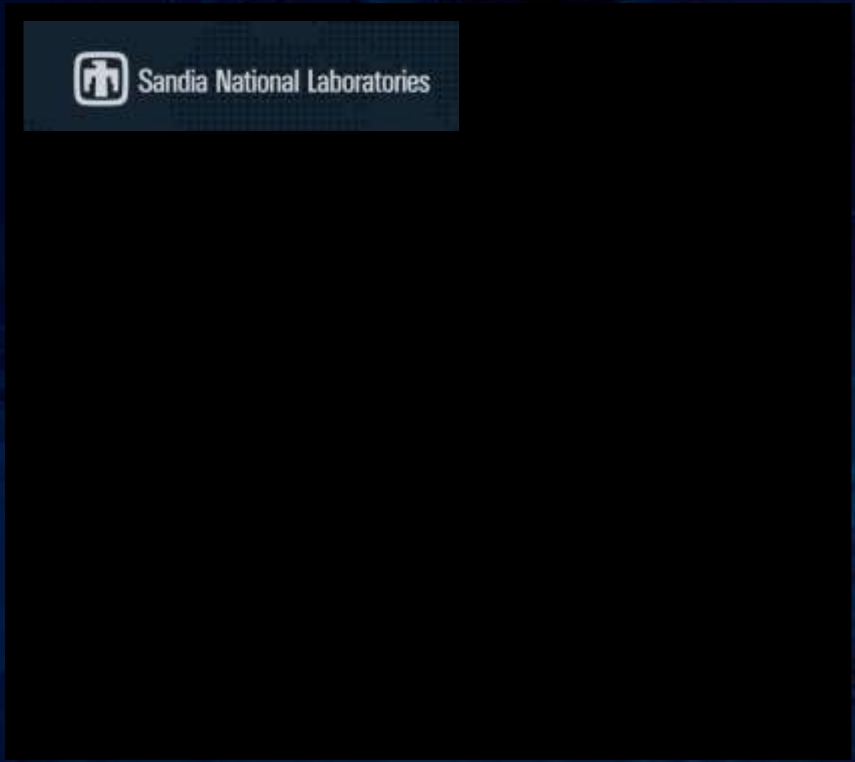
Synthetic Aperture Radar: VideoSAR (long-dwell modes processed differently)



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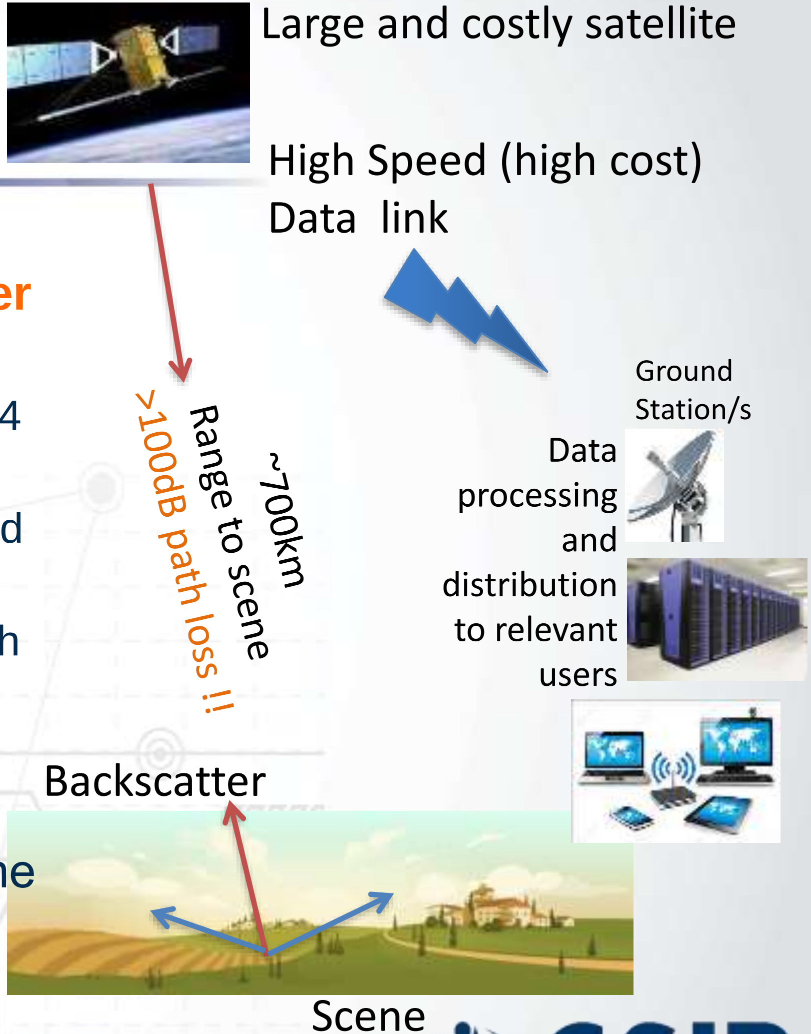
How do we make SAR even more cost effective?

- **Radar Imaging requires a moving platform**
- Satellite SAR sensors are **big, heavy and power hungry**
  - Scene is ~700 km away resulting in very large R^4 pathloss!
    - Requires a design using **Large Antennas** and **High Tx Power**
  - Imaged is very large to make the investment worth it - **data storage on satellite needs to be huge**
  - Data has to be **downlinked to earth via a high bandwidth link**
- However … a change in approach can overcome many of these challenges for applications of a local nature (such as farming, infrastructure monitoring, community security, mining, etc)



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The alternative
Bistatic SAR Systems

A disruptive solution: Leave the Transmitter in space, **but** …. ***put the receiver close to the scene to be imaged***

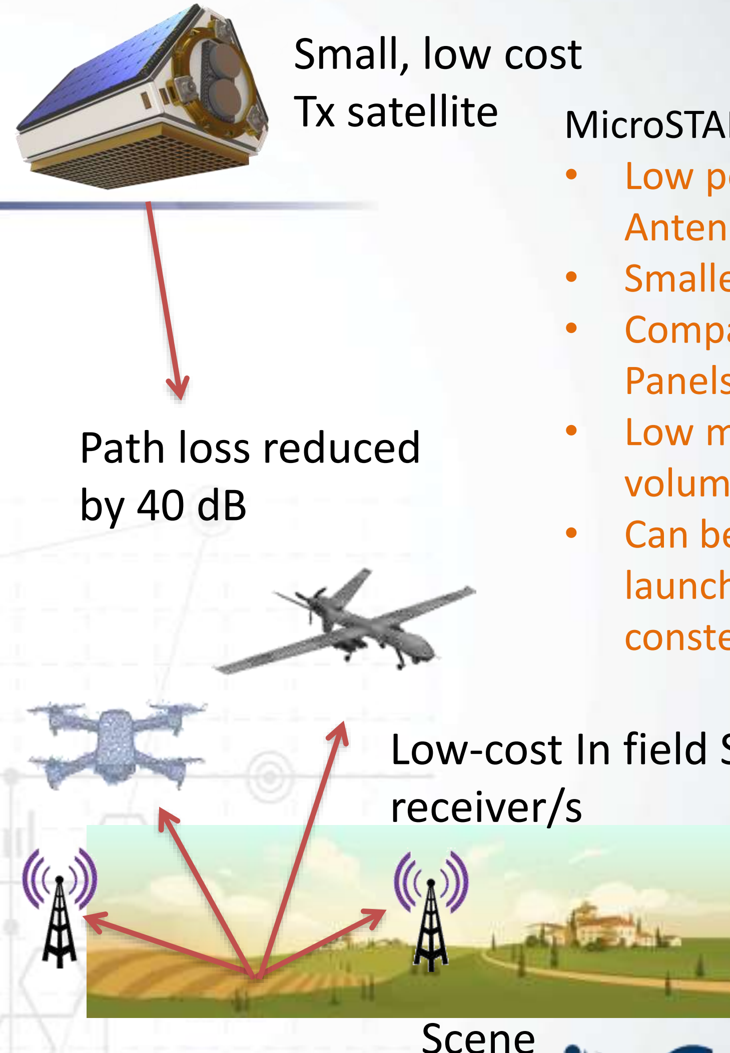
For a scene up to 5 km away form the receiver, the **path loss is reduced by up to 42 dB!!**

This saving allows the space segment to use

a small Tx only satellite that needs

- **no receivers**
- **no data recorders**
- **no high speed data links**
- **and consumes much less power**

MicroSTAR satellites can be launched in constellations significantly reducing launch costs and increasing revisit time!



MicroSTAR SAR TX:

- Low power Tx Antenna
- Smaller antenna
- Compact Solar Panels
- Low mass and volume
- Can be launched in constellations

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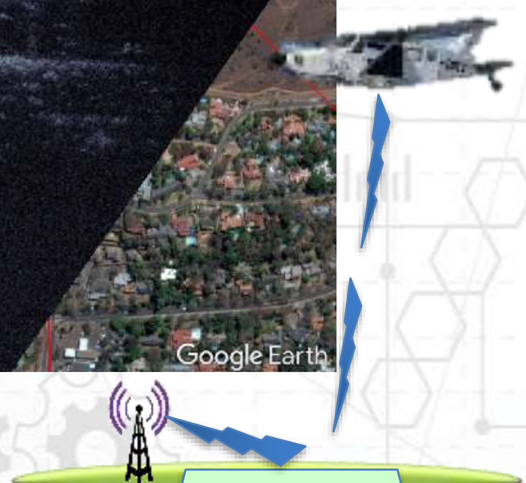
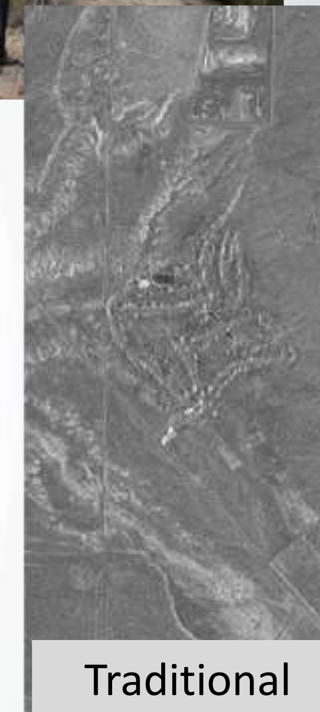
Does it work?

Initial CSIR proof of Concept using airborne transmitter (2016)





Sandia National Laboratories

Technical Report - Yocky, Wahl, Jakowatz 2014

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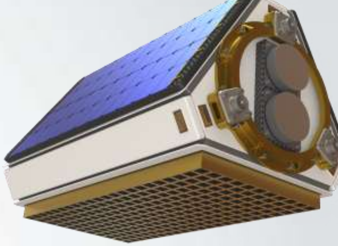
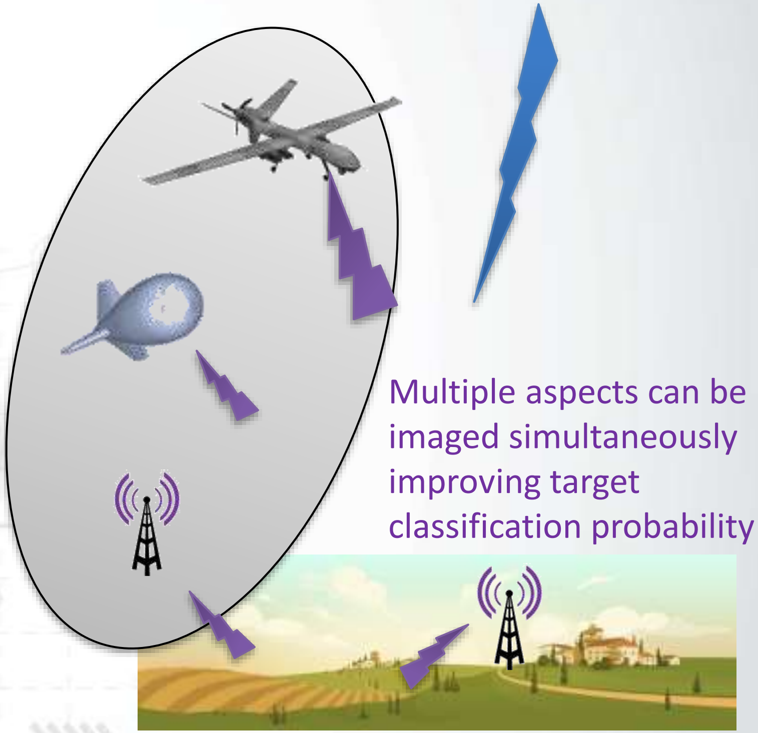
Advantage of Bistatic SAR (1)



- **Stationary receivers** can **now** create SAR imagery!
  - handheld devices,
  - mast / high site mounted sensors,
  - Aerostat radars can now produce radar imagery
  - Even on high ship masts such as oil tankers for maritime surveillance
- The SAR receiver is **PASSIVE (receive only) and cannot be detected via ESM**
  - imagery can be formed covertly for military and security applications
  - Multiple aspects can be imaged at once!
- **No downlink costs**
- **Image formation at the site**
  - 3rd party does not see your data



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Advantages of Bistatic SAR (2)

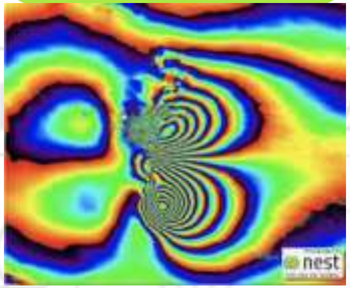
Zero Latency imaging!

VideoSAR

- To the ground based receiver, the illumination always looks like it is long-dwell

Single pass interferometry

- Multiple antennas at receive site allows for every pass to produce interferometry



Continent level Coverage every pass

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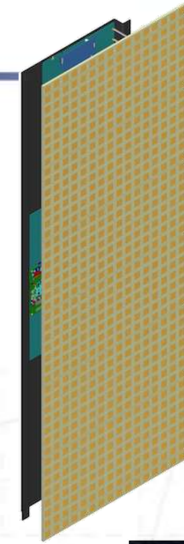
The MicroSTAR : Micro Satellite Transmit ARray

- A lower cost first step in spaceborne radar for South Africa

> With the potential to unlock a whole new industry similar to what GPS did for positioning !

- Based on C-Band Array technology being developed for monostatic spaceborne SAR at CSIR
- < 100 kg satellite
- Constellation ready
  - 16 to 20 satellites could provide near continuous coverage of Southern Africa



MicroSTAR: Transmit Modes

Tx Modes

Wide access:

- StripLight
- ScanLight

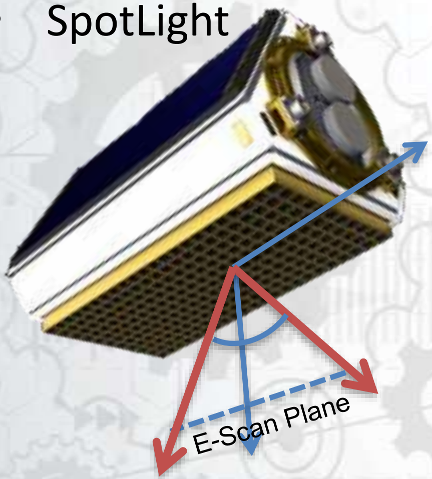
High resolution

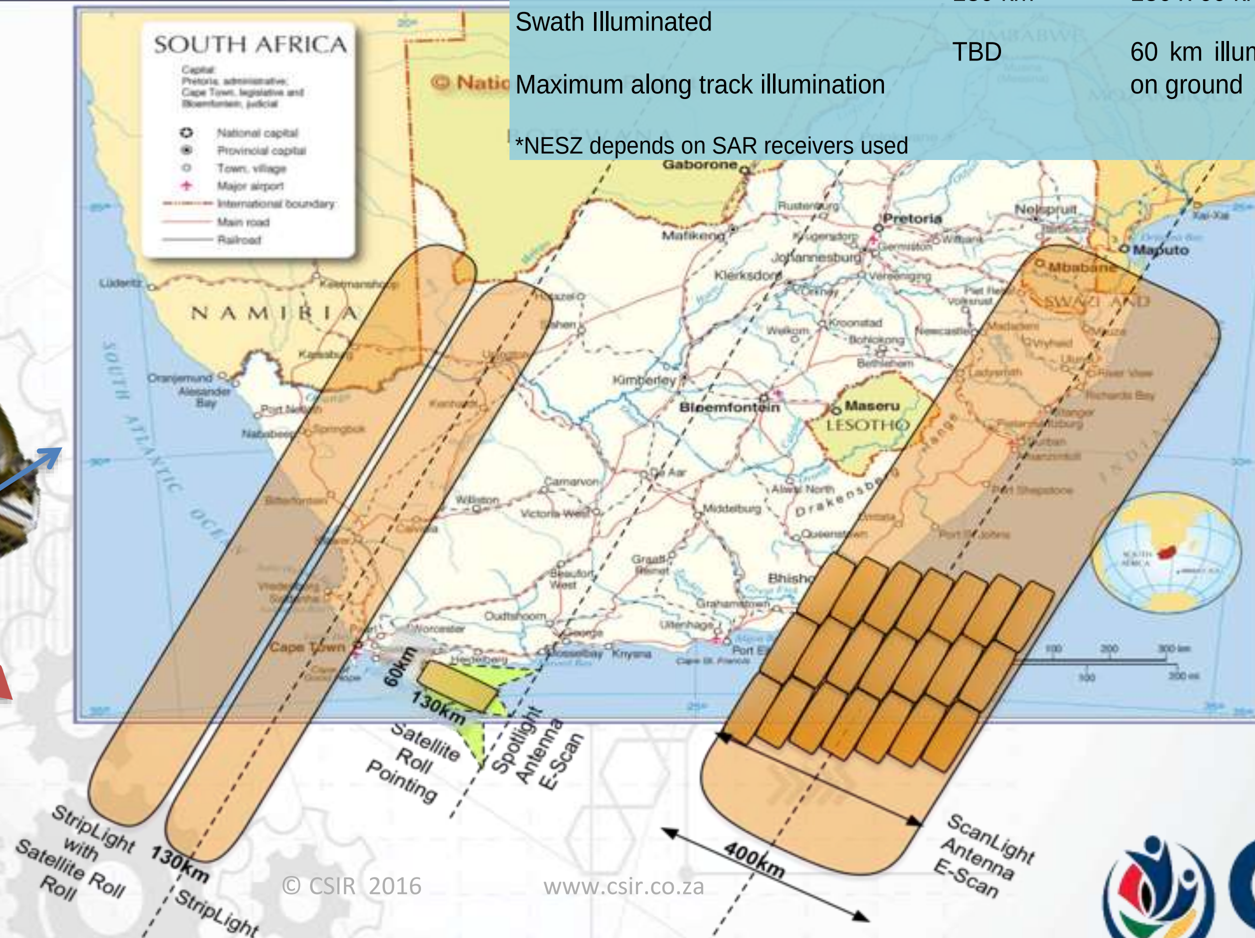
- SpotLight

Summary of MicroSAR Tx Modes

Mode	StripLight	SpotLight	ScanLight
· Achievable NESZ* (dBsm/sm)	<-20	<-20	<-20
Achievable Ground Resolution	5 x 5 m	1 x 1 m	~ 20m
Swath Illuminated	130 km	130 x 60 km	400 km
Maximum along track illumination	TBD	60 km illuminated on ground	TBD

*NESZ depends on SAR receivers used





MicroSTAR:
Potential Applications

Military Surveillance and targeting – forward forces can form covert SAR imagery of scene even though they are stationary

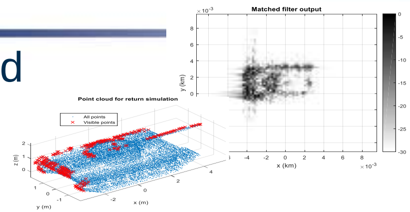
Close to Shore Coastal Surveillance - 20 to 30 km detection of small vessels using existing cell tower Infrastructure

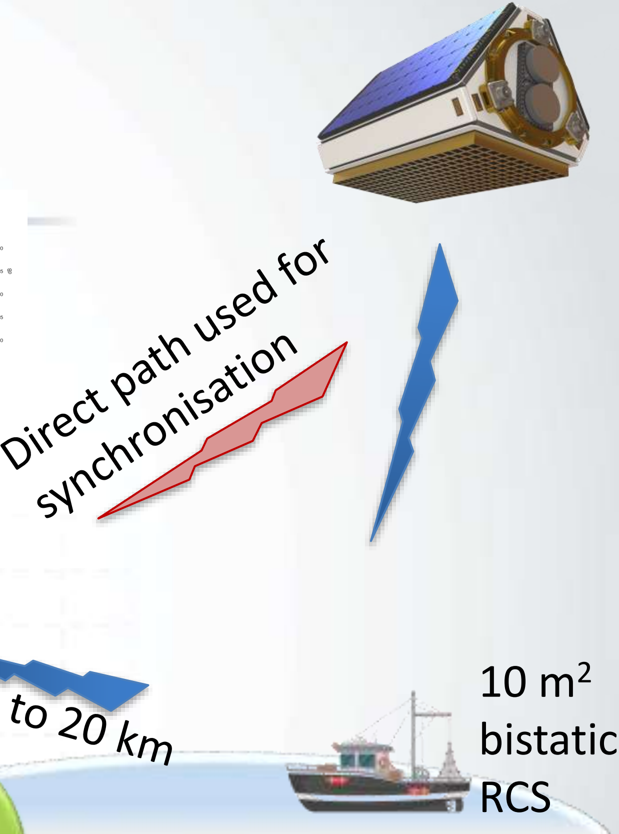
Agriculture – the farmer has his own receiver on a mast – no need to pay for data every month! Data is collected where required!

Maritime – large vessels can have passive surveillance without being detected by pirates

Mining – Subsidence monitoring for safety from stationary receivers

Infrastructure – monitoring of dam walls, bridges, roads, etc, all form the cell tower closest to the infrastructure!





Typical horizons of a radar sensor looking over flat terrain are listed below

Height of Receiver	10m	100m	1000m
Max Scene Extent * *dependent on Receiver design	13 km	40 km	130 km

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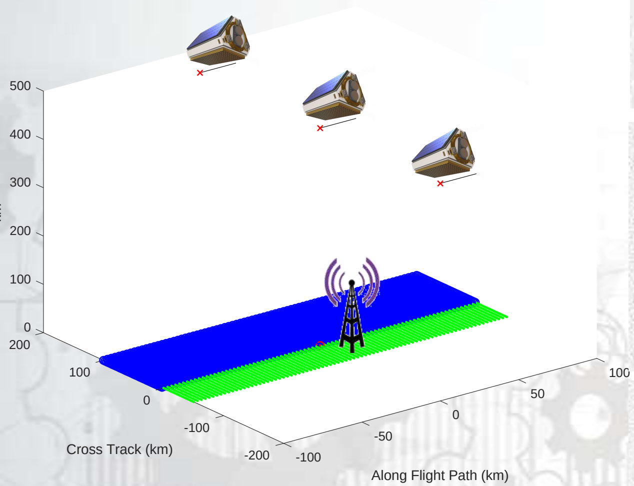
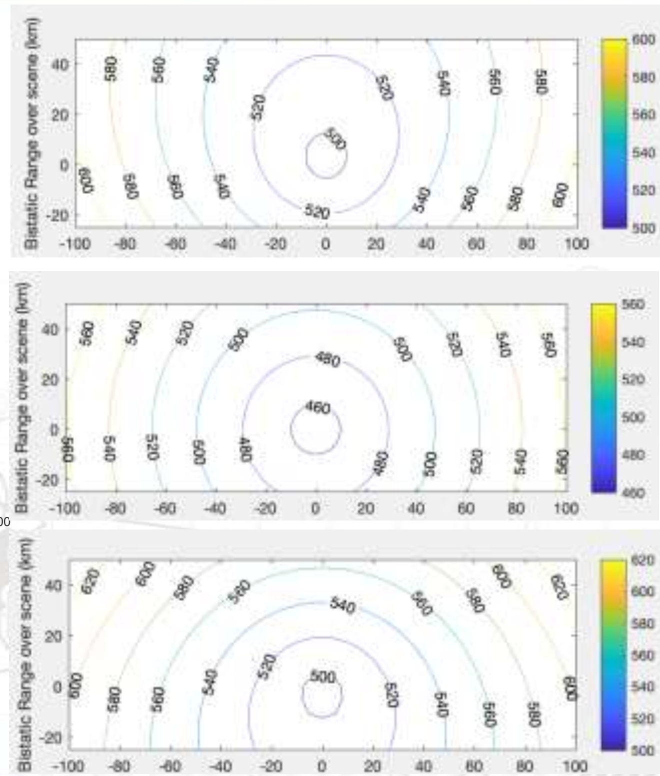
Bistatic SAR - Geometry effects

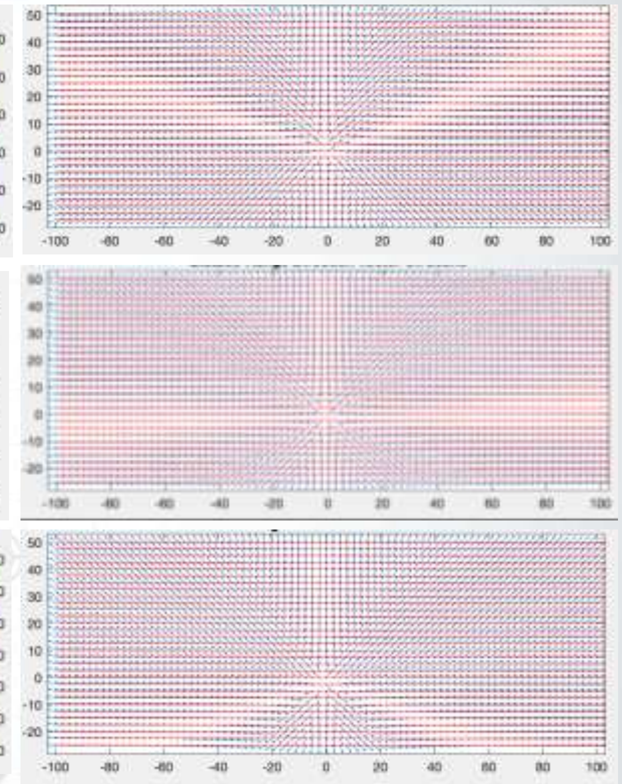
Striplight SAR Mode
Resolution 10m



Bistatic Range



Bistatic Gradient Vectors



Satellite position:

- (1) 200km over the sea
- (2) Directly overhead
- (3) 200 km over land

Velocity parallel to coast

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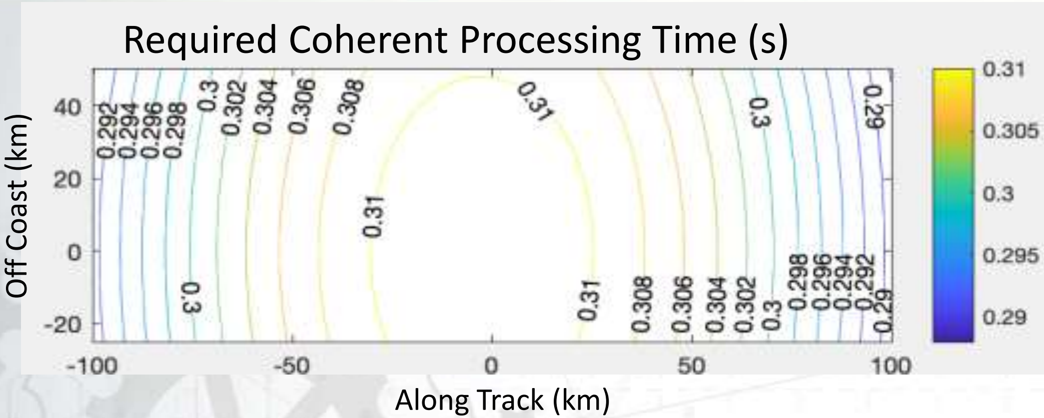
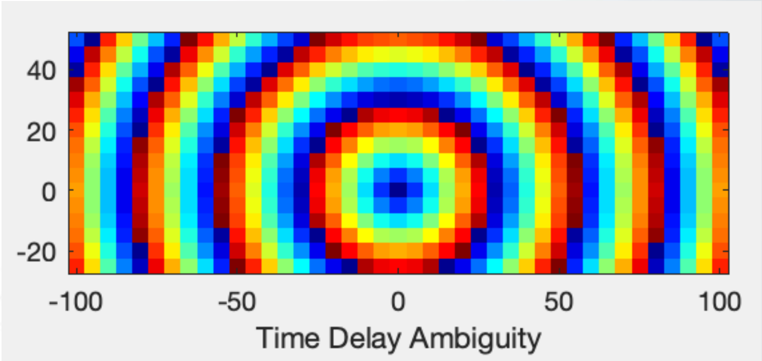
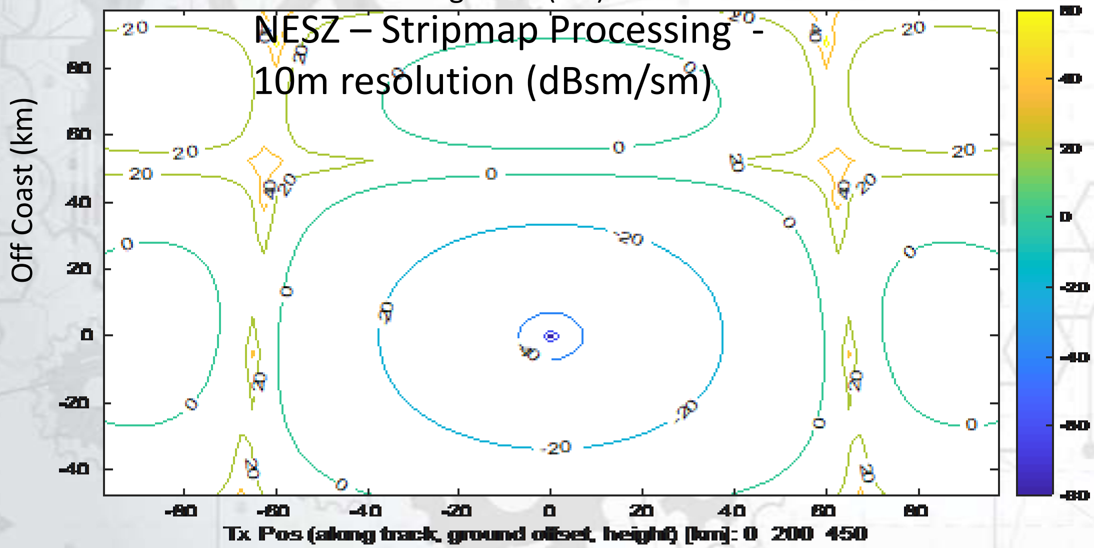
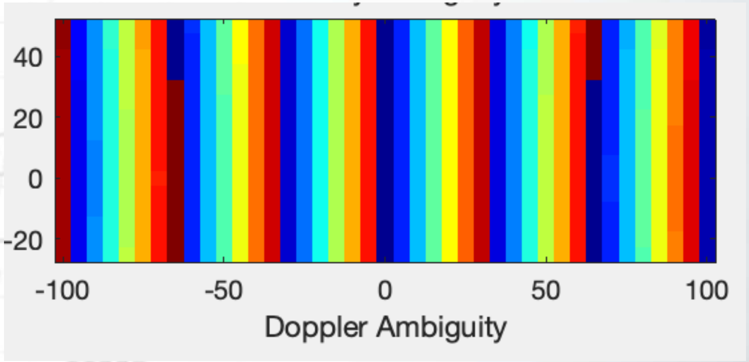
Bistatic SAR Performance









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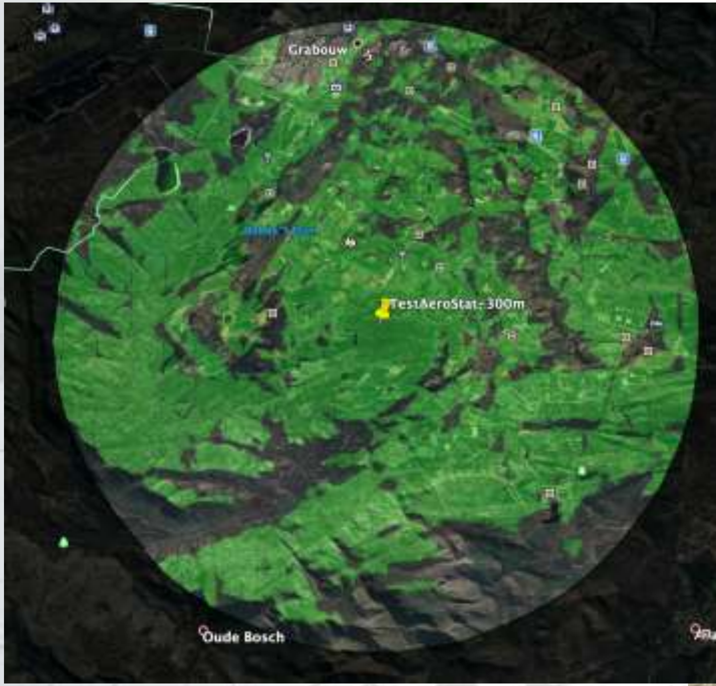
Possible Vodacom / MTN (smaller insert) receiver sites across South Africa

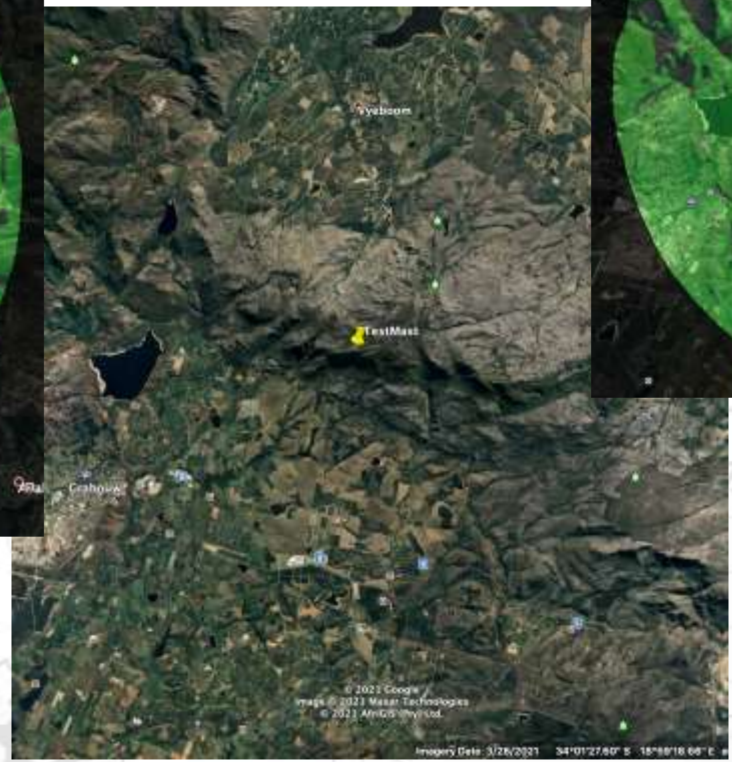
Source: nperf.com

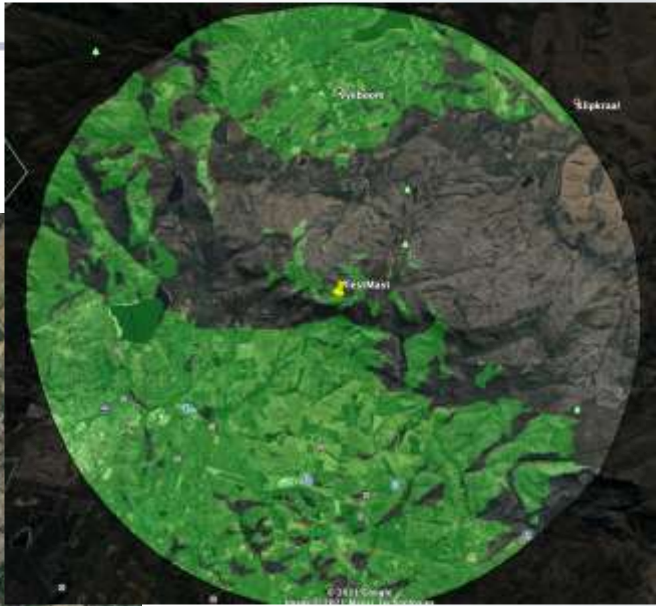
Example coverage over Grabouw High Value Agriculture area



300m tethered balloon/aerostat with 30kg payload (Optics + MicroSTAR Rx)

Possible Test Site for Agriculture Grabouw





20m Mast on mountain

- Optics (for reference)
- MicroSTAR receiver
- Comms

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Won’t receivers cost an arm and a leg

Current SAR imagery prices is around **ZAR 10 - 20k per image** for the new low cost micro-satellite SAR systems

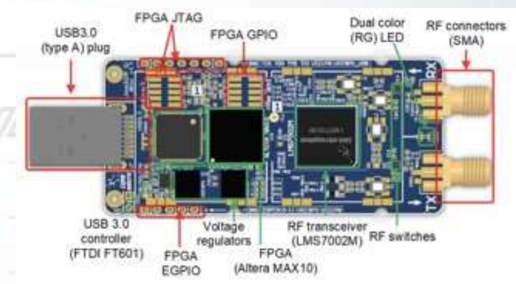
The advent of Wifi and SDR has brought down receiver costs significantly. This combined with the cost of AI GPU computing developed for self-driving cars has plummeted the cost for a MicroSTAR receive station.

Example:

- AIR-T SDR Processor Card is 5.5k USD as COTS
  - Dual Receive Channel SDR with integrated FPGA/GPU and CPU
  - Should achieve roughly 1.5 to 2m resolution bistatic SAR imagery

Custom receivers produced at scale could rival the cost of mono-static SAR imagery per image

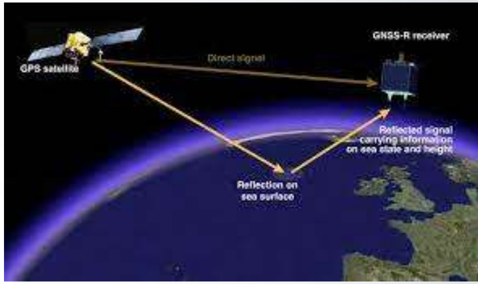
Potential to turn SAR into a everyday consumer item



What about other transmitters?

Passive bistatic SAR

- The field of passive bistatic SAR has also developed with several studies exploring options for passive bi-static SAR
  - GNSS, Satellite TV Broadcasts, Starlink / Oneweb
- **GNSS bandwidth not sufficient for high resolution imaging**. SNR is also somewhat low. Applications could include ocean monitoring and such, where much lower resolution can be used. (CSIR radar group did a GNSS reflectometry study in 2015/16)
- **Satellite TV Broadcast** are typically too low power and low bandwidth – and due to geostationary orbit cannot really be used to create a synthetic aperture. There are some concepts to place special SAR satellites in a semi geostationary orbit. These would be very large satellites as they geostationary orbits are typically 36000 km away.
- **Starlink might be** an option from a bandwidth point of view, but comms coding and signal power density remain an issue for high quality imaging.
- The **advantage of a dedicated constellation of radar transmitters** include:
  - **Control of the transmit signal**, its ambiguity function and its power density to some extent (as allowed by a cost effective design)
  - **Active control of the beam and waveform** to illuminate areas of interest depending on the task – Stripmap, Spotlight (and VideoSAR) and ScanLight modes to address different requirements in different geographical areas
  - **Encoding of the Tx signal** with parameters to make the imaging task easier for the receiver
  - **C-band or X-band** could have the advantage of much lower cost of receiver components at present
  - Same might be true if we switch to automotive radar components – but atmospheric losses is likely a killer for such millimeter wave ideas



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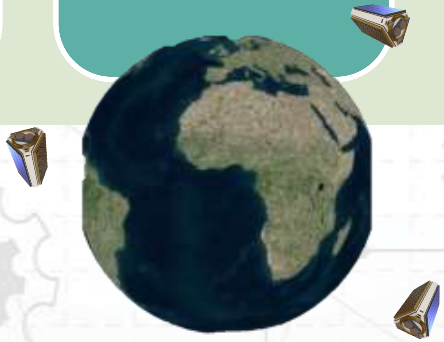
What Next?

A South African (African) endeavor with a Global market?

- Bistatic SAR ***will (soon) disrupt traditional SAR markets and business models***
- ***Are we going to be part of this SAR revolution?***

Develop Bistatic SAR Applications → Create low-cost SAR base stations / receivers → Develop and a launch a path finder mission → Demonstrate **niche applications** and **show benefits** → **Scale Globally**



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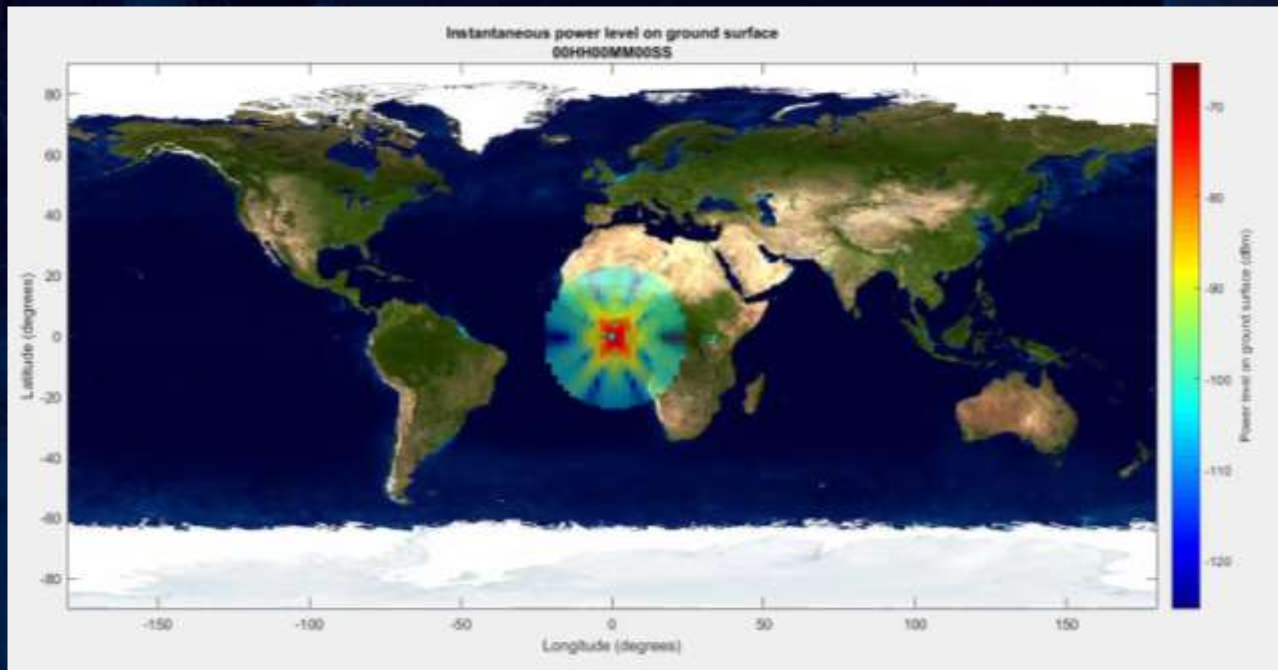
Thank you !!



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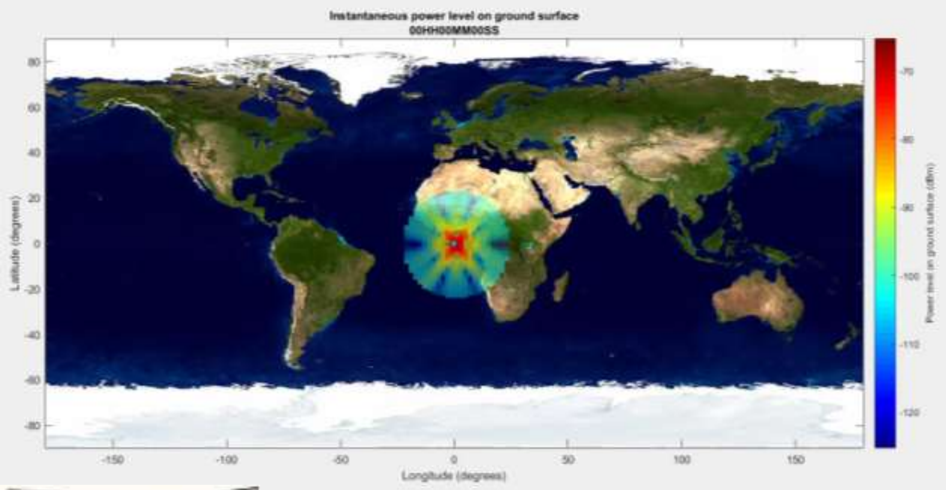
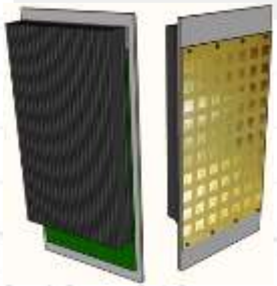
CSIR technology in place to design, analyse and develop MicroSTAR

- Bistatic SAR performance modelling tools
  - Imaging geometry effects on Resolution, SNR, etc
  - Detailed capability to predict performance given receiver specifications (including moving receivers)
- Signal processing to produce bistatic imagery
- Receiver Technology
  - Low cost dual channel receivers manufactured in SA
- Transmit array technology
  - For the development of the space segment transmitter
- Receive array technology
  - For more advanced receivers such as DoD / Silent UAV applications
- Radar Design and Manufacture capability





C-Band Phased Array Transmit Panel

C-Band Dual Channel Receiver

Low cost
Highly integrated
COTS control

Key new technologies
✓ PCB based RF
✓ Customisation at assembly

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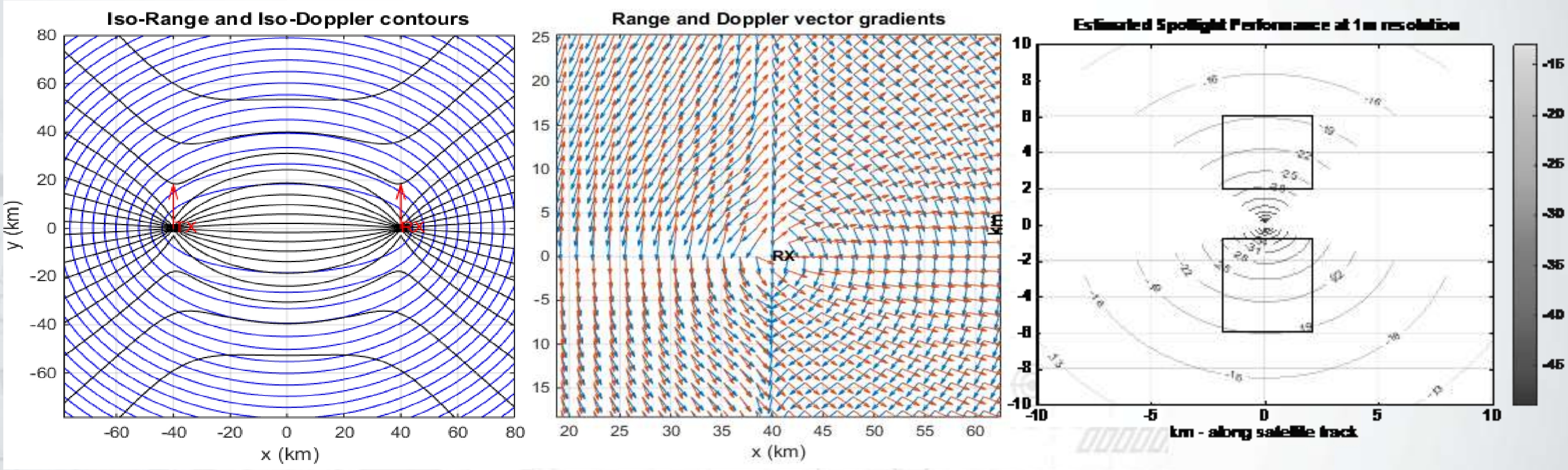
Bistatic Geometry
Radar Performance Simulator



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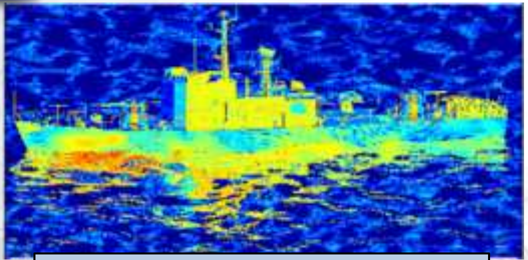
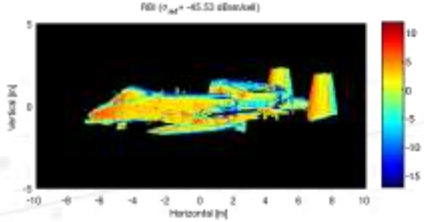
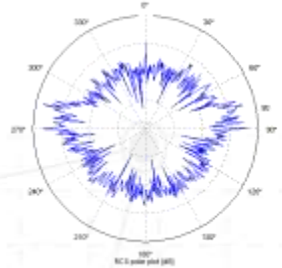
Signal level simulation and processing of bistatic SAR

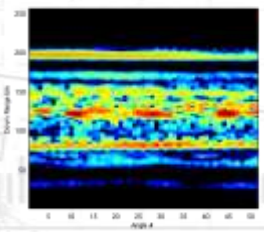
SigmaHat In-house EM modelling tool

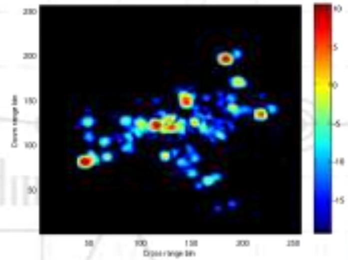


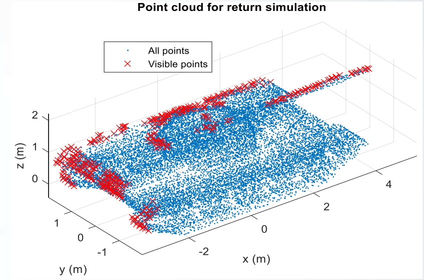
Example: Real Beam Image showing main RCS contributions

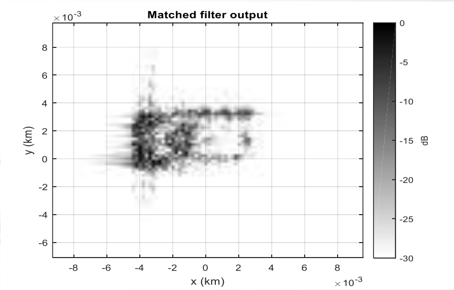


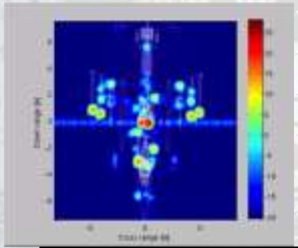












ISR from simulated radar returns

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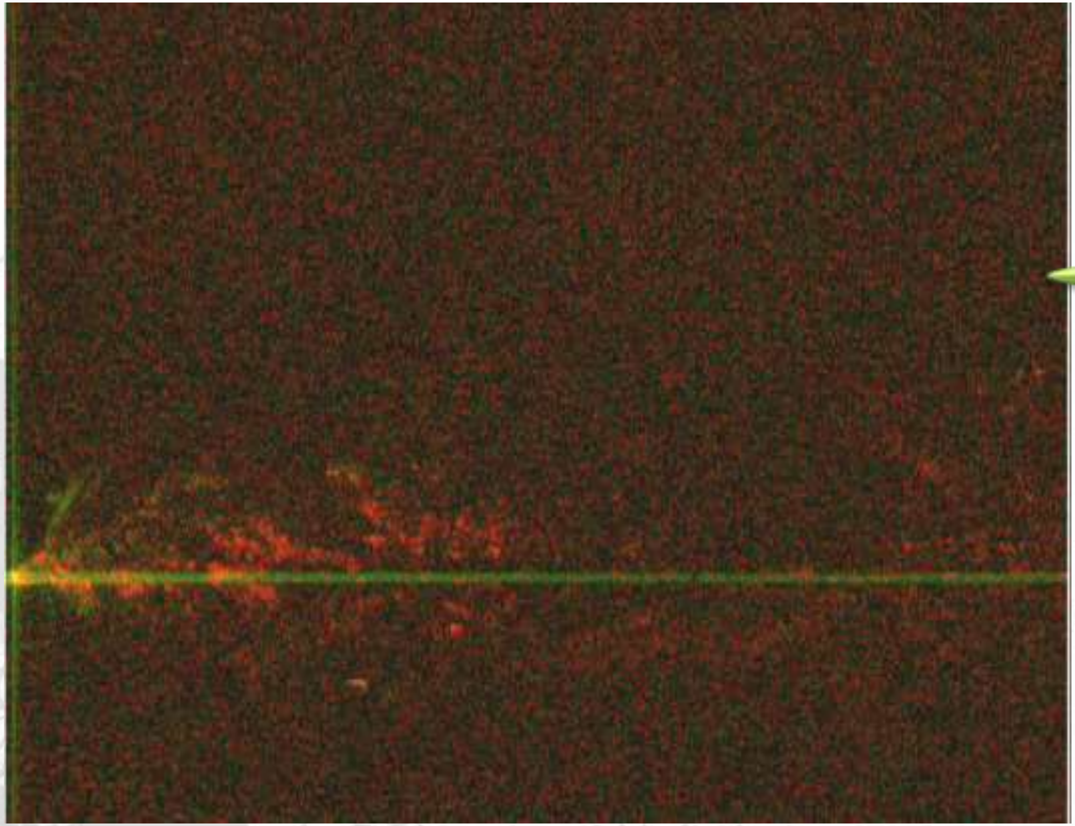
Towards MicroSTAR
Initial CSIR proof of Concept (2016)



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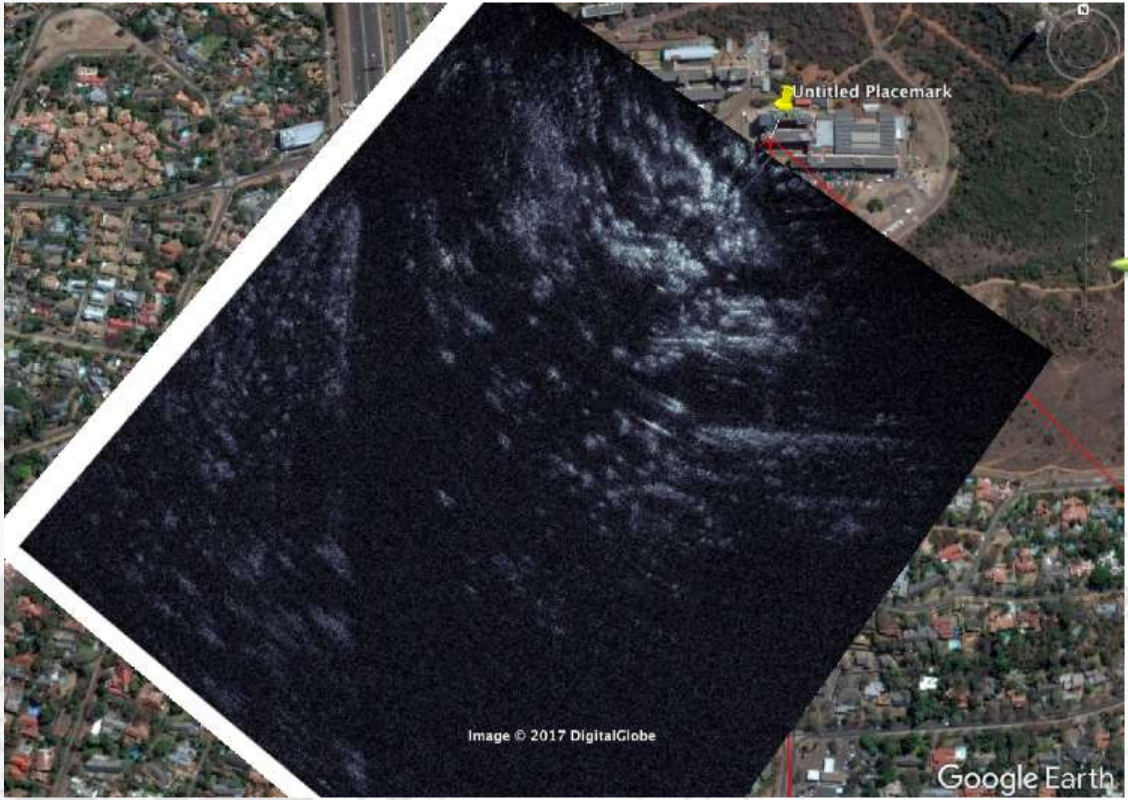
Towards microSTAR
Initial CSIR proof of Concept (2016)



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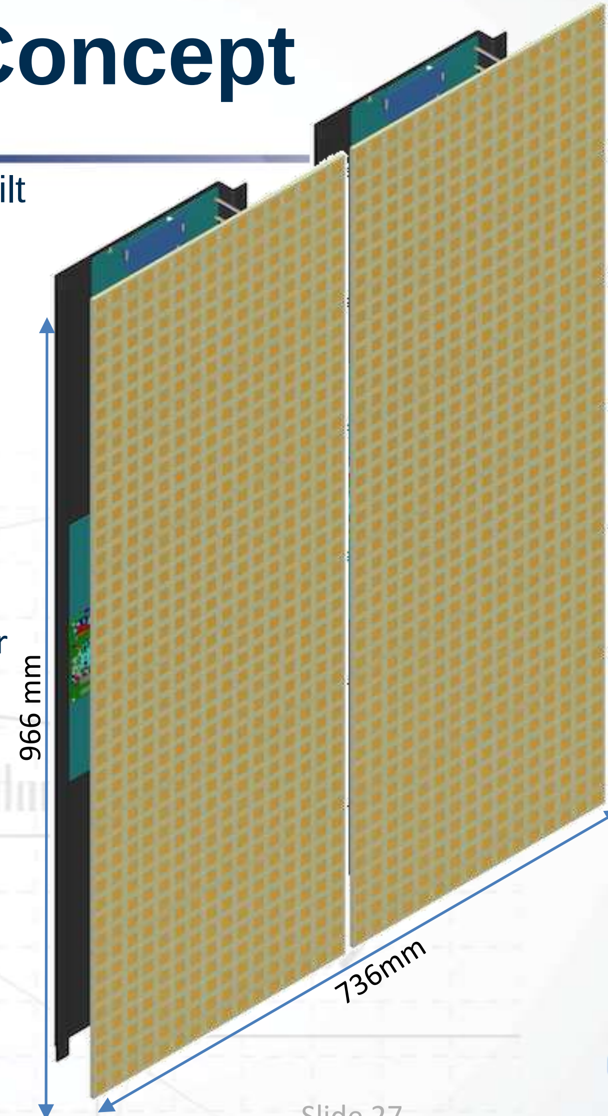
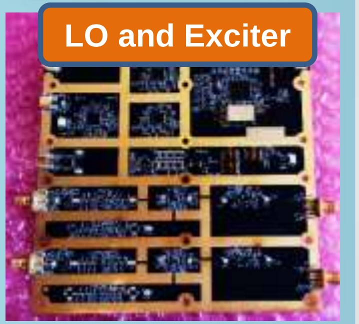
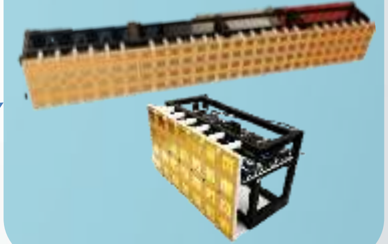
MicroSTAR Tx Array Concept

- First MicroSTAR concept demonstrator can be built on SAR-C Sub-array
  - One or Two sub-arrays would provide adequate Tx power and gain
  - Ready Technology from SAR-C project
  - Reduces overall manufacturing cost when it comes to constellation
- Sub-array Specifications
  - 42 Rows in single axis phased array
  - C-band with up to 300 MHz bandwidth
  - ~20 Watt per column (Peak)
  - ~530W Peak Radiated Power per sub-array (after losses)
  - 20% duty cycle
- Sub-array Size (Active Aperture)
  - 966mm across track (e-scan direction)
  - 368mm along track
- Sub-array Beamwidths
  - 3.5 deg x 9 deg (single sub-array)
  - 3.5 deg x 4.5 deg (dual sub-array)



C-Band Technology Base





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Close to shore MDA using MicroSTAR
First order SNR using Doppler Processing

Parameter	Value		Unit
	1 sub-array	2 sub-arrays	
Target RCS	10		m^2
Satellite Altitude	400		km
Satellite Velocity	7600		m/s
Max Range (Tx) assumes 300 km Sat track offset	540		km
Tx Gain (1,2 sub)	31	34	dBi
Tx Peak Power (1,2 sub) (after losses)	530	1060	W
Rx Gain (assuming multi-channel sector array)	21		dBi
Rx Noise Figure	5		dB
Rx Losses (other)	5		dB
Tx Bandwidth	25		MHz
Single Pulse SNR (1 sub, 2 sub)	-53	-47	dB
SNR Pulse Doppler Processing (300 ms CPI)	**11**	**17**	**dB**
Potential non-coherent gain	**7**	**5**	**dB**

Typical horizons of a radar sensor looking over flat terrain are listed below

Height of Receiver	10m	100m	1000m
Max Scene Extent * *dependent on Receiver design	13 km	40 km	130 km

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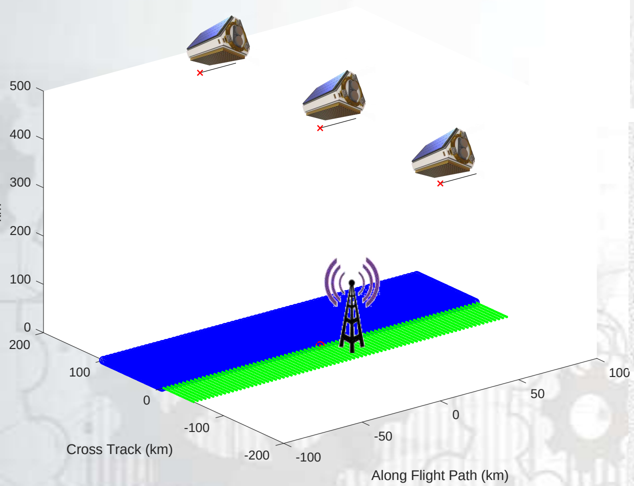
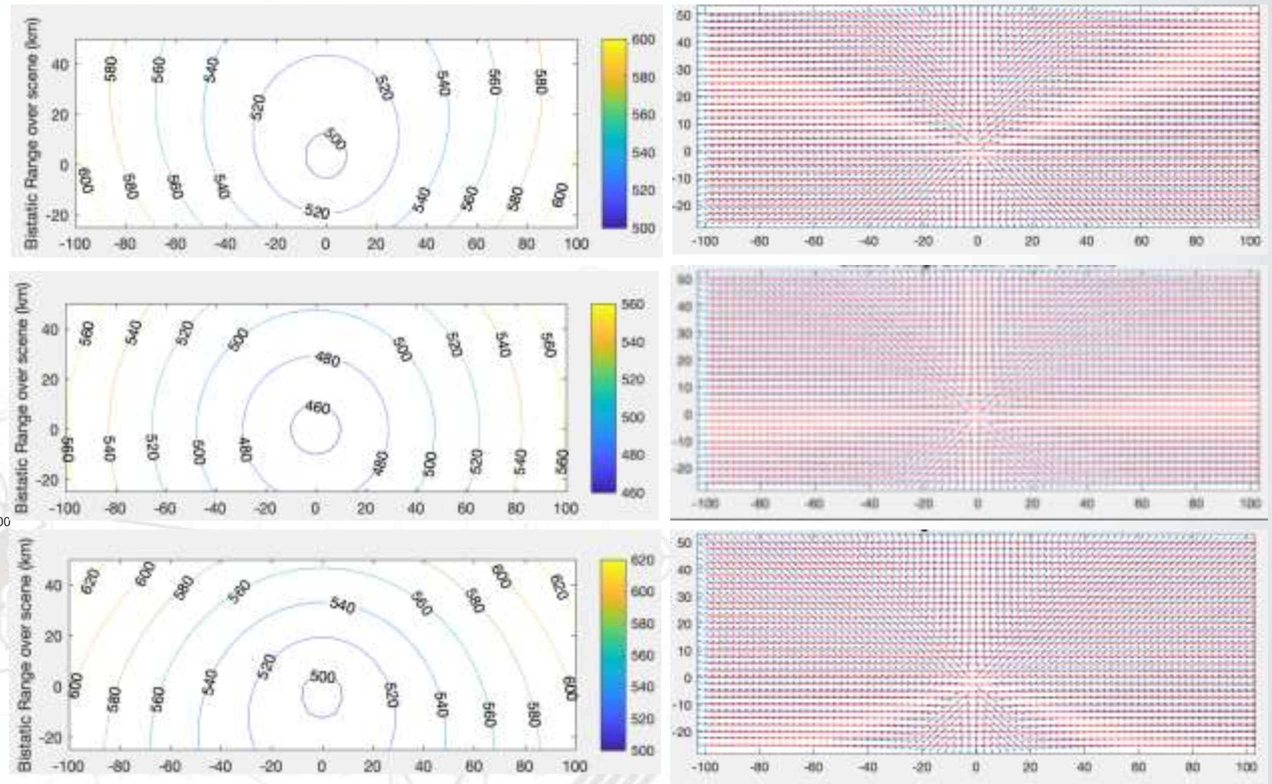
Bistatic SAR - Geometry effects

Parameter	Value	Unit
Striplight SAR Mode		
Resolution	10	m



Bistatic Range

Bistatic Gradient Vectors

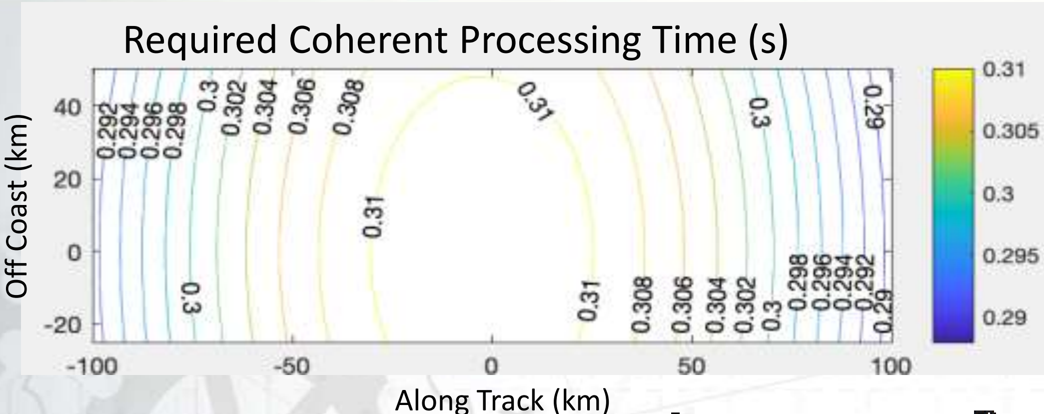


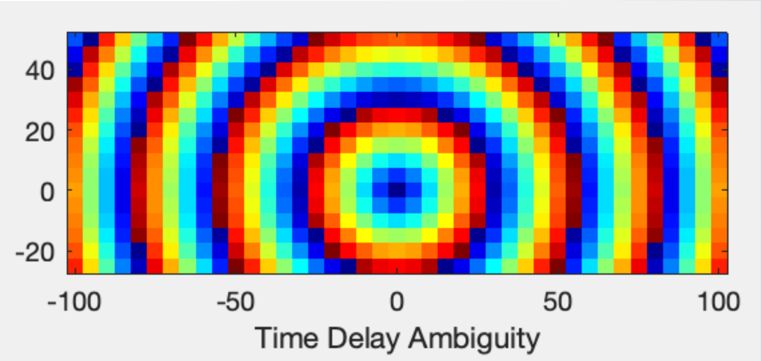
Satellite position:

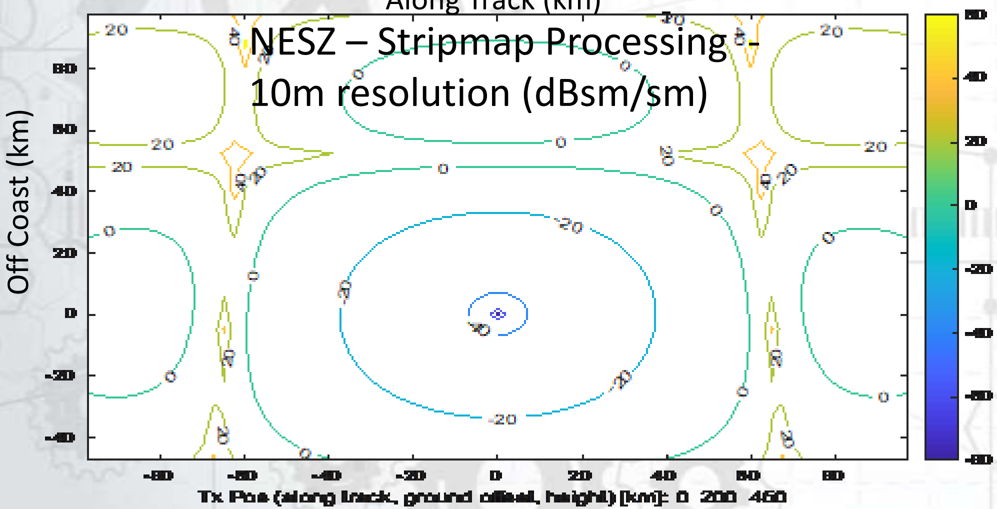
- (1) 200km over the sea
- (2) Directly overhead
- (3) 200 km over land

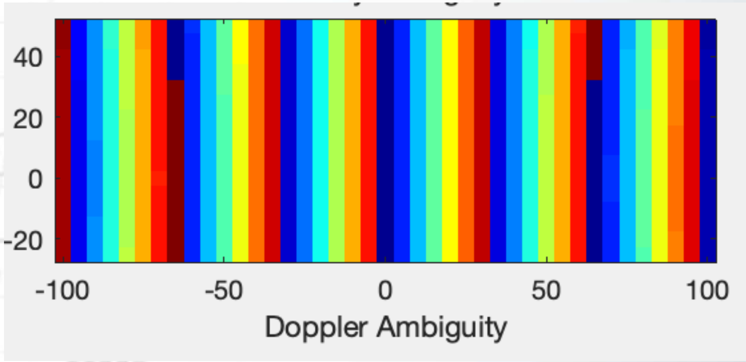
Velocity parallel to coast

Bistatic SAR Performance







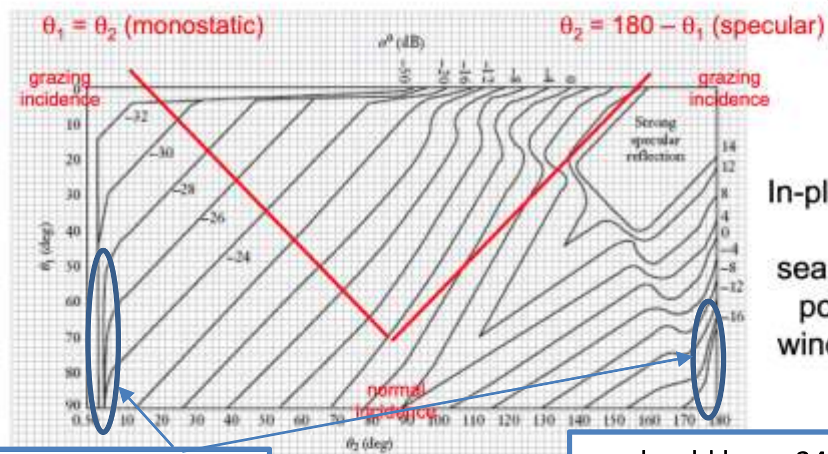


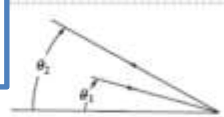
Bistatic Clutter

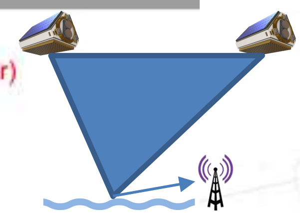
Reference:
Bistatic Radar Clutter
Simulations using
Scattering Phenomenology
Saba Mudaliar

Bistatic Clutter

Reference:
Bistatic Radar Clutter
Lecture Notes - Prof Chris Baker





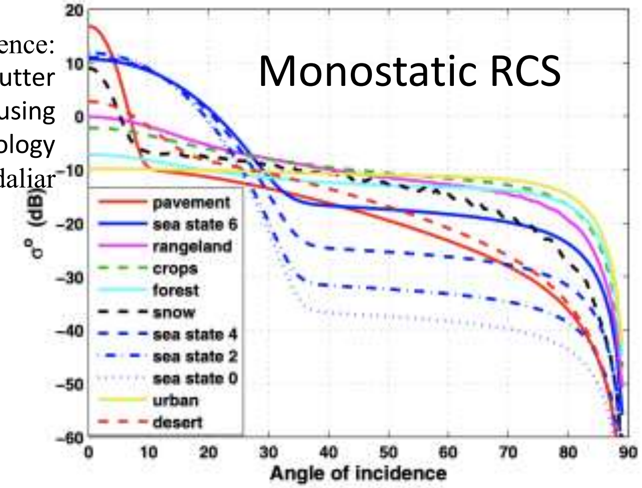


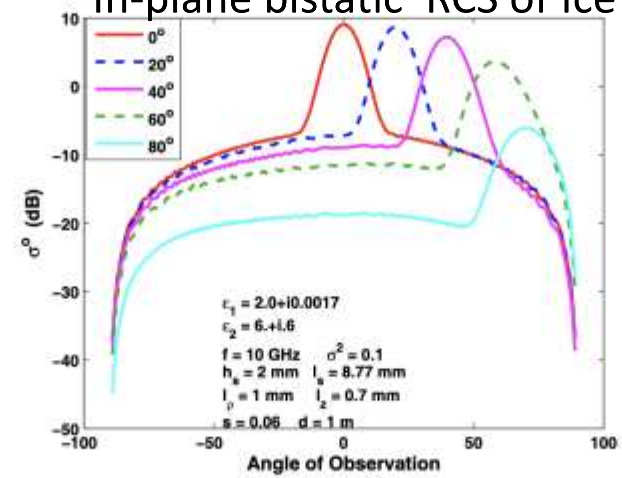
In-plane, X-band

sea, horizontal polarisation, wind speed 20 knots

MicroSTAR should operate here

σ_0 should be < -24 dBsm/sm for near normal incidence and near grazing detection (backscatter) or <-16 dBsm/sm (forward scatter)





Domville, A.R., 'The bistatic reflection from land and sea of X-band radio waves', GEC (Electronics) Ltd., Memo SLM 1802, Stanmore, England, July 1967.

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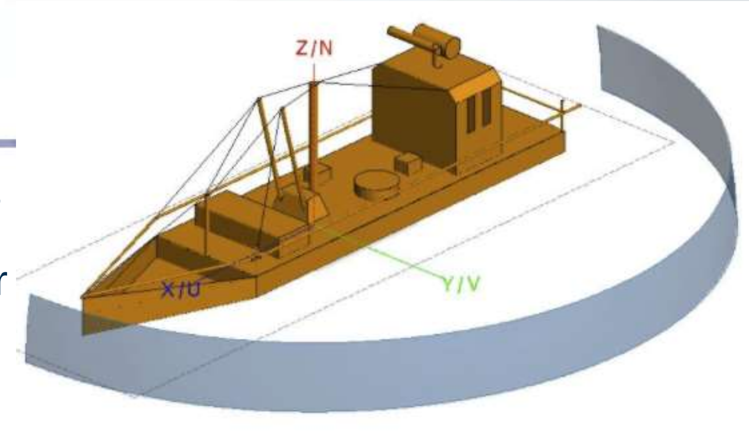
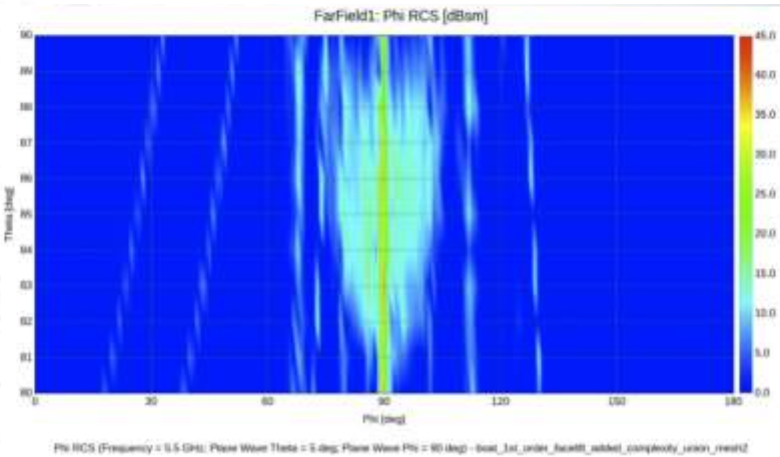
Discussion

- Both a Pulse-Doppler or NESZ based analysis show that close to shore targets with RCS of 10 dBsm should be detectable using a relatively low cost ground based radar receiver
- To further prove and analyse the concept there are several issues that would need to be addressed
  - Bistatic RCS of **target** and **clutter** to enable a signal to clutter calculation (It is noted that the bistatic RCS of a fishing vessel here might be considerably lower than the equivalent monostatic configuration)
  - **Effect of multipath** (which has been ignored here, but should not be worse than for a normal monostatic shore based radar)
  - Detailed **analysis of synchronization** and its effect of system noise floor
  - Effect of **polarization:** Either the transmitter or receiver might have to allow dual polarization to ensure adequate performance
- The topics will be explored in future studies





First Order FEKO modelling indicates between 0 and 10 dBsm
{Thanks to Jacques Cilliers and Monique Potgieter}

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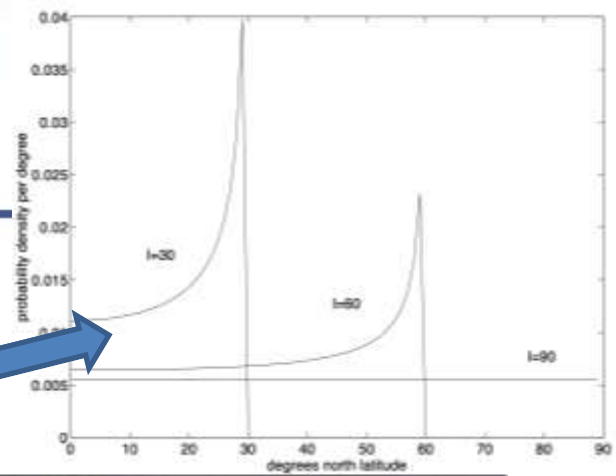
Close to shore MDA using MicroSTAR Satellite Constellation Considerations

Many questions that need to be answered with regards the satellite design

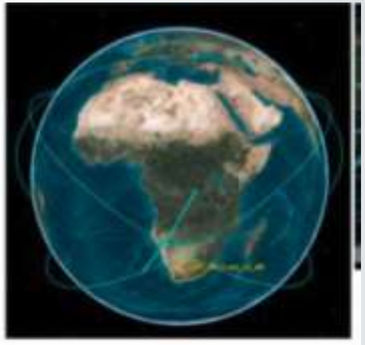
- How many satellites would be required to achieve a useful revisit time considering illumination of the RSA coastline
- Will this provide utility elsewhere?
- How far off-track should the satellite be able to illuminate
- Does it make sense to consider narrow and wide swaths to allow detection of ship traffic from other platforms and to allow ocean current monitoring?
- Would a small satellite be capable of generating enough power onboard?

Constellation considerations

- A single satellite in polar orbit allows imaging in any part of the world at least twice daily
- The South African coast line falls within -35 degree latitude. By placing the satellite in this inclination you gain the advantage that the satellite spends most of its time at the extreme latitude, reducing access time
- Combining of roll and electronic steering, the illuminator can track RSA coastline when it comes within range
- This orbit and control allows up to 7 accesses per day at a particular receiver site
  - A first order analysis (done before radar performance modelling) assumed a maximum acceptable off axis angle of 67 degrees and a satellite altitude of 700 km
  - This indicated that a revisit time of < 90 min to the SA coast can be attained with three satellites (using three different launches – see RAAN numbers)
- An alternate solution with around 45 degree off axis scanning at lower altitude with 3 or 4 satellites per launch should will should in hourly updates
- Interestingly, then northern reaches of these orbits pass over the Mediterranean, the Middle east, India and parts of China, whilst Australia and norther parts of South America will also receive good coverage



Reference:
Earth Coverage by Satellites in Circular Orbit
Alan R. Washburn
Department of Operations Research
Naval Postgraduate School



Inclination	36deg
Altitude	700km
No of Sats	3
RAAN's	90; 210; 330
Slant angle max	62deg

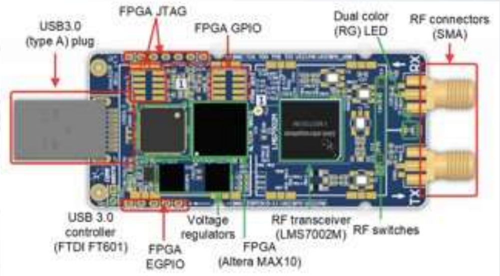
But won’t receivers cost an arm and a leg

Current SAR imagery prices is around ZAR 10k per image for the new low cost micro-satellite SAR systems

The advent of Wifi and SDR has brought down receiver costs significantly. This combined with the cost of AI GPU computing developed for self-driving cars has plummeted the cost for a MicroSTAR receive station.

Example:

- AIR-T SDR Processor Card is 5.5k USD as COTS
  - Dual Receive Channel SDR with integrated FPGA/GPU and CPU
  - Should achieve roughly 1.5 to 2m resolution bistatic SAR imagery



Custom receivers produced at scale could rival the cost of mono-static SAR imagery

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MicroSTAR concept:
Possible Tx Modes

Summary of MicroSAR Tx Modes

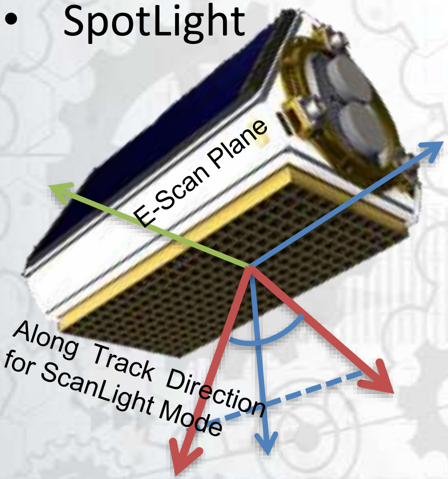
Mode	StripLight	SpotLight	ScanLight
· Achievable NESZ* (dBsm/sm)	<-20	<-20	<-20
Achievable Ground Resolution	5 x 5 m	1 x 1 m	~ 20m
Swath Illuminated	130 km	130 x 60 km	400 km
Maximum along track illumination	TBD	60 km illuminated on ground	TBD

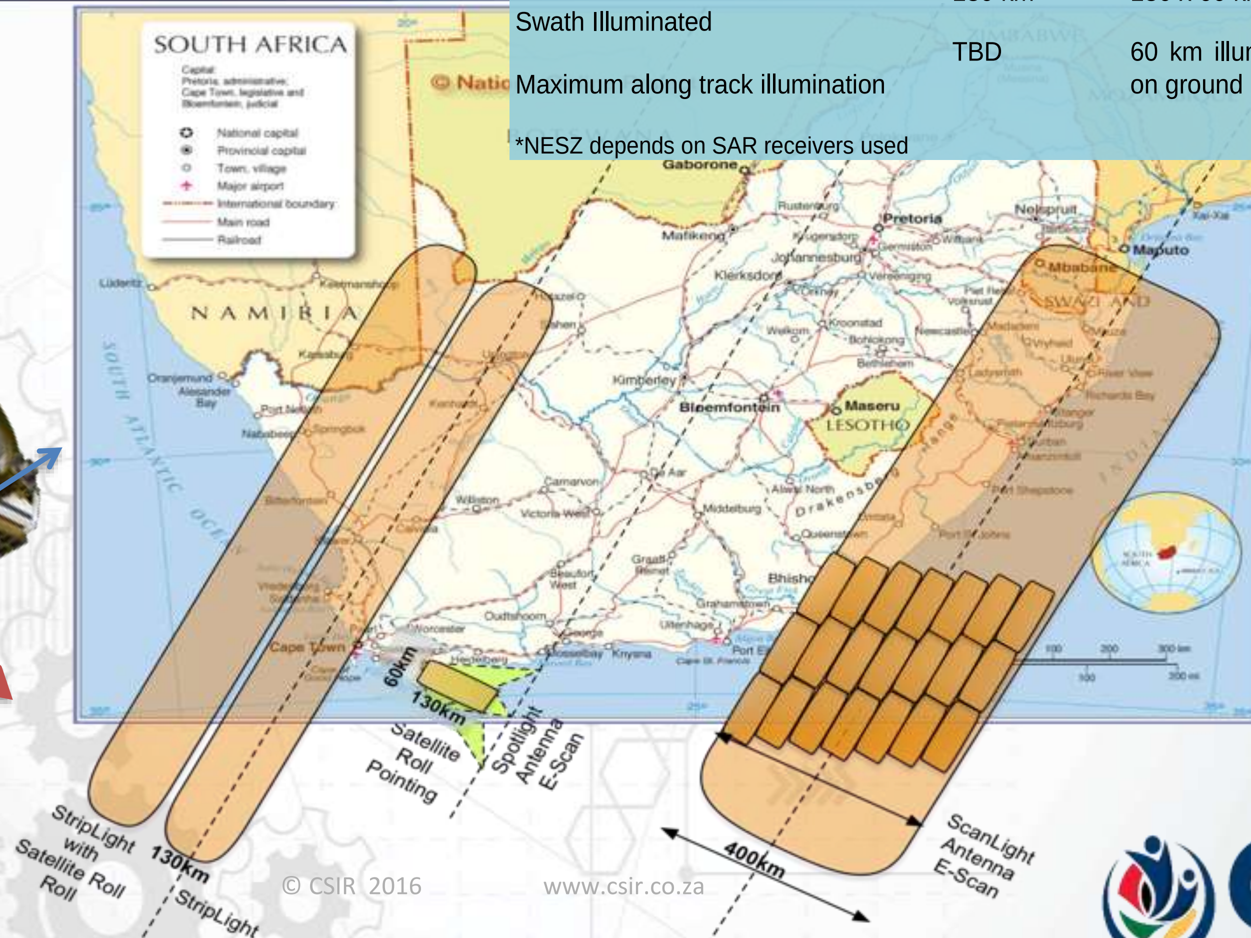
*NESZ depends on SAR receivers used

Tx Modes

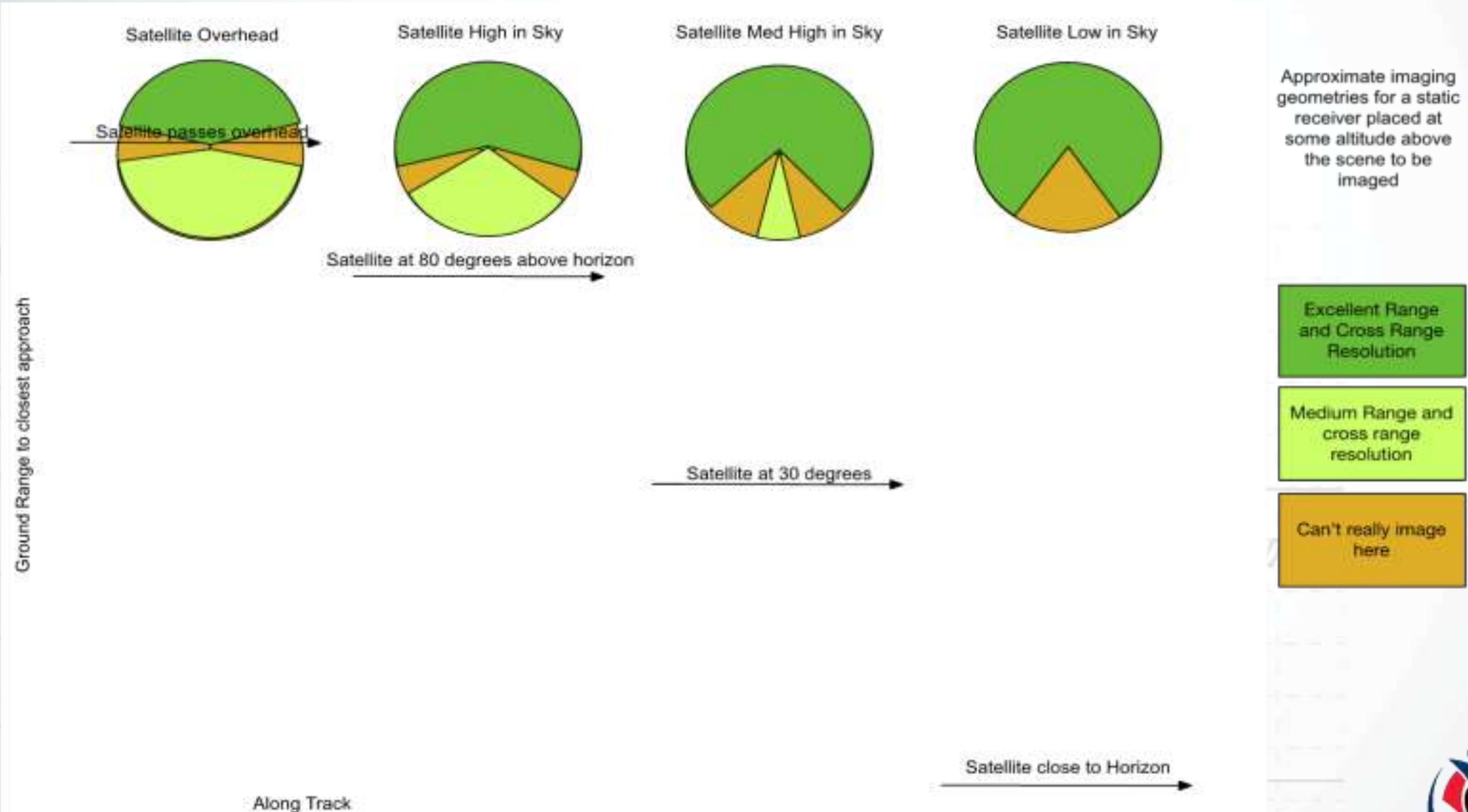
Wide access:
- StripLight
- ScanLight

High resolution
- SpotLight





Some Implications of the Bistatic Geometry



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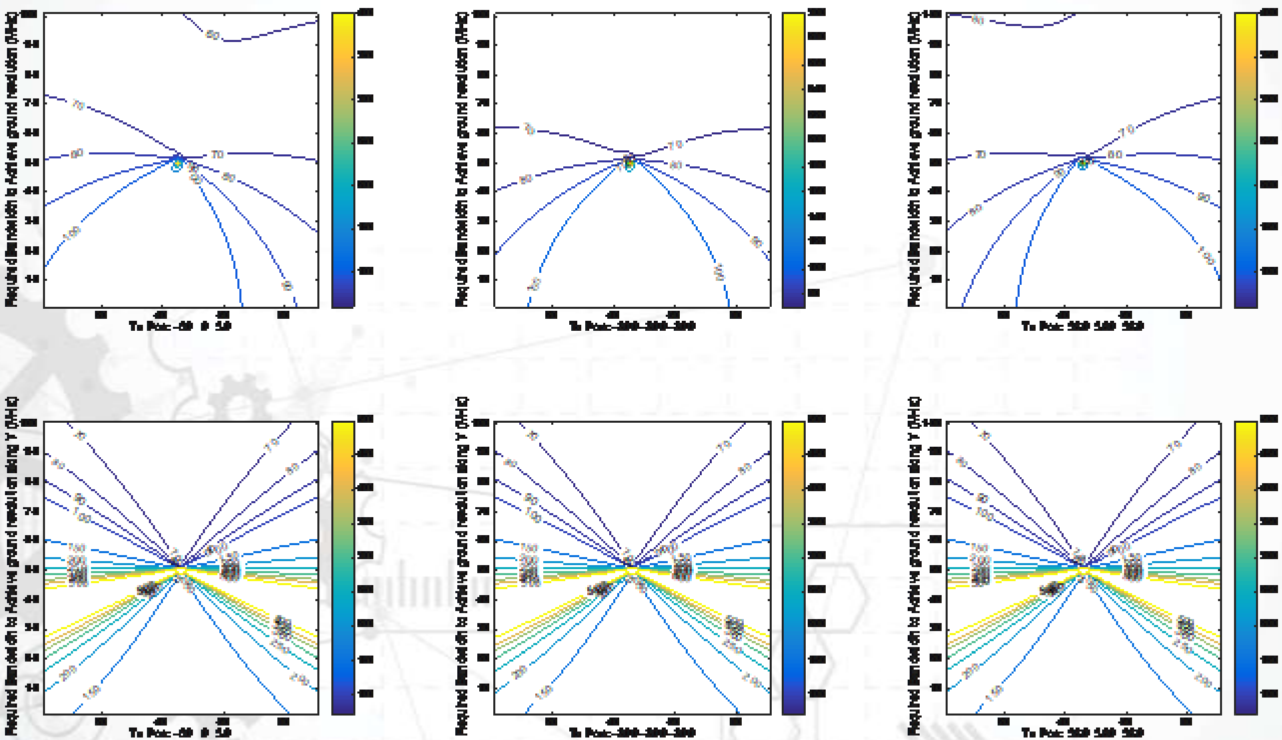
Bandwidth Required to achieve Resolution



Bandwidth required to achieve 5m Range Resolutiuon on the ground

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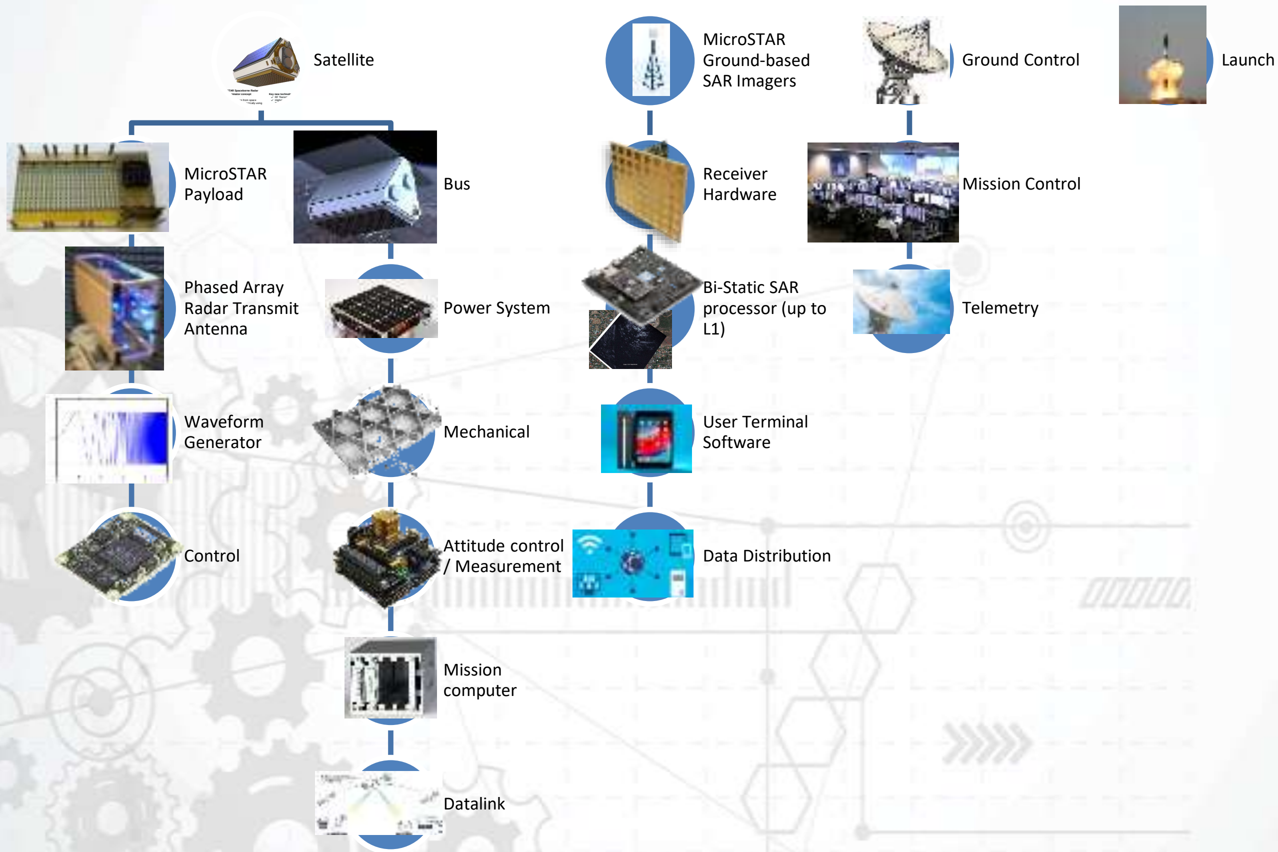
Main System Elements



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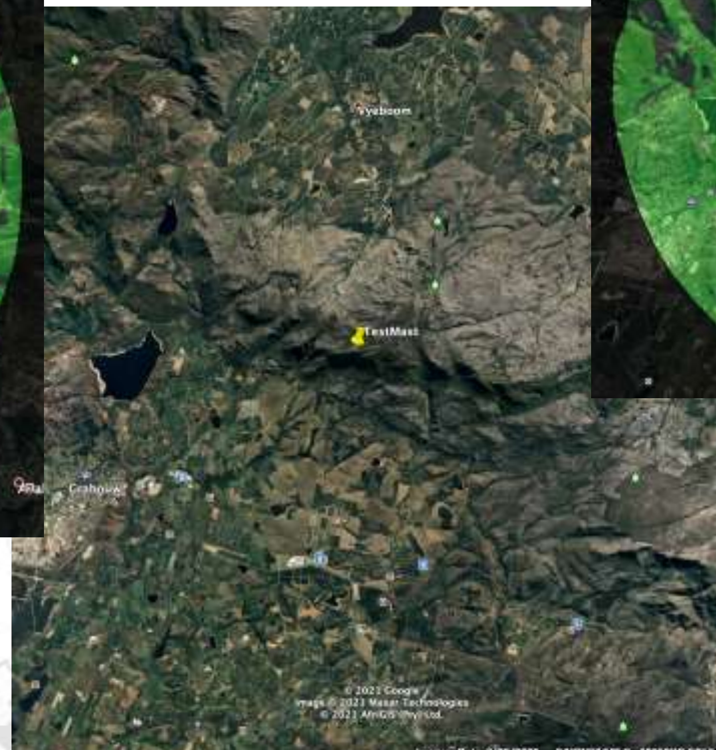
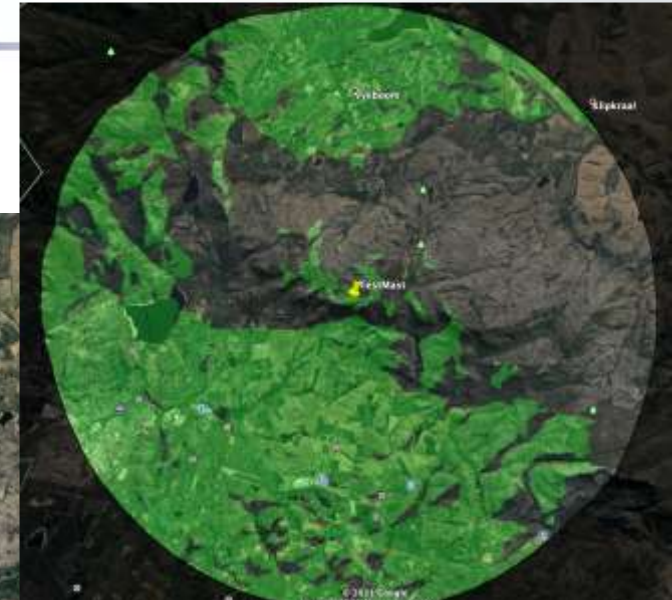
Remember – Maritime surveillance will not be the only application!

300m tethered balloon/aerostat with 30kg payload (Optics + MicroSTAR)

Possible Test Site for Agriculture Grabouw





20m Mast on mountain
- Optics (for reference)
- MicroSTAR receiver
- Comms

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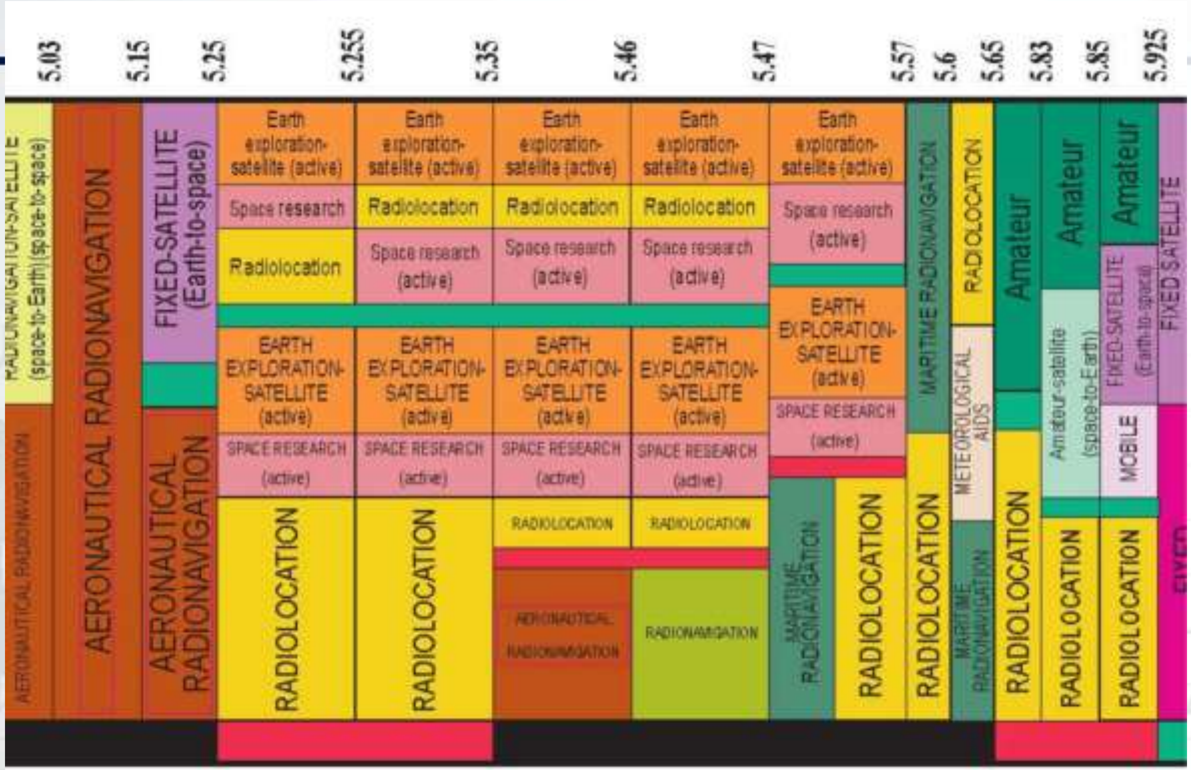
Can we access the spectrum?



FCC Spectrum regulations in C-Band allocates 5.25 to 5.57 GHz as Earth Exploration and 5.65 GHz to 5.92 GHz as spectrum for Amateur satellites, with the bands between that also being allocated to Radiolocation.

It could stand to reason that a satellite like MicroSTAR that will effectviely be a very low access very low power density on the ground be able to access all of the bandwidth between 5.25 and 5.92 GHz, which amounts to a maximum bandwidth of ~700 MHz

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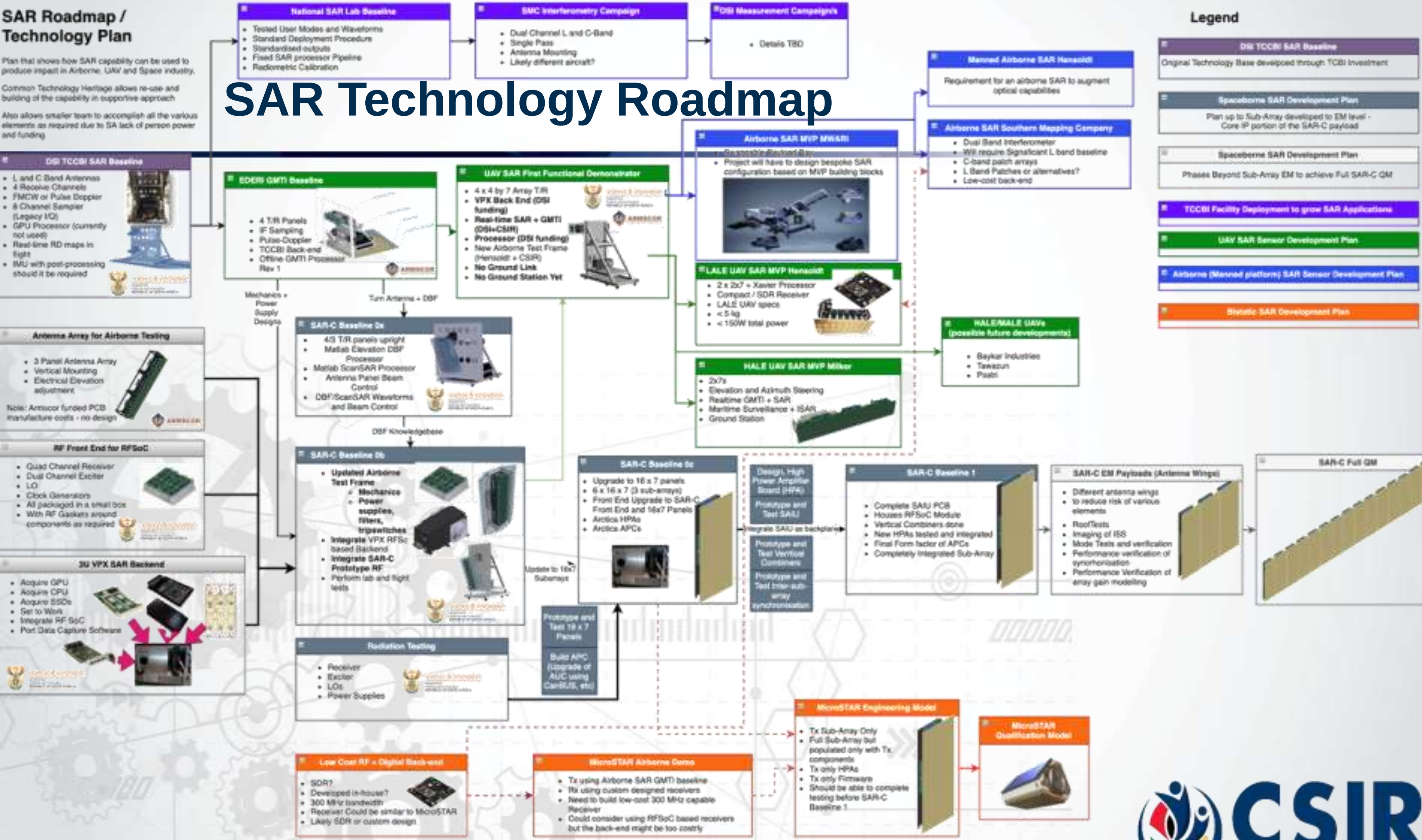
SAR Technology Roadmap



Receiver sites – how cheap can we make them

- Much of the cost of a radar does not go into the radar itself but into
  - Power supply system (Solar with battery backup / 220V, Generator, etc)
  - Antenna Mast
  - Radar Shelter
  - Internet access
  - Security from theft, vandalism, etc
- MicroSTAR receiver sites will also require such infrastructure
  - To keep initial costs low, would be best to piggy back on other infrastructure
  - Advantage – Antennas can be stationary, Power consumption is low (only Rx)
- Cell towers could potentially be well suited sites
  - Already chosen for wide coverage
  - Already provides basic needs
    - Power, equipment shelter, security, internet connection
  - Are already deployed where there are a lot of human activity
- Save significant cost in terms of infrastructure as a start
- MicroSTAR receivers can also provide beneficial information to cell providers
  - Effectively producing a radio coverage map by producing a SAR clutter map image….

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Possible Vodacom / MTN (smaller insert) receiver sites across South Africa

Source: nperf.com

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Pathfinder C-band system development program

Airborne Tx, Ground based Rx, Application R&D

Note: Ideally include Cell Tower based Rx sites

Phase 1 –
ROM R15-30 million
12-18 months

Launch pathfinder mission on low-cost rideshare

Specify, Develop, Intgerate, Test and Qualify Space Segment (EM, QM, FM)

Specify and Develop / Procure Ground / Naval Rx Stations

Identify potential partners for receiver station sites

Phase 2
ROM R150-300 million
(incl launch costs)
24-30 months

Pathfinder application demonstrations for military and commercial applications

Update space segment design – including design of constellation

Reduce cost of groundbased receivers through scaled production

Updated requirements for constellation mission

Production designs for satellite and ground segment

Phase 3
ROM TBD –
expect R50-100 million
Will depend heavily on amount of redesign required

Constellation mission

Phase 4
Constellation mission Commercialisation

Start earning return on investment

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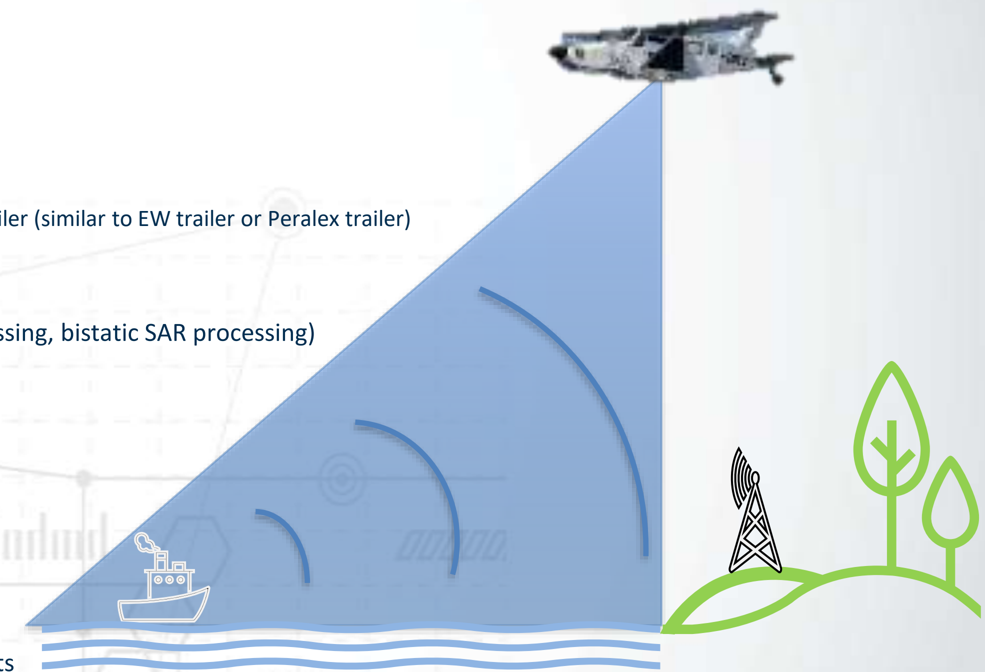
Phase 1 (12 – 18 months)

- PoC design and system engineering
  - Identify test sites and launch applications
  - Performance modelling for launch applications
  - Specifications for RX site equipment
- Development of Rx site equipment
  - Develop / Acquire support equipment needed for mobile Rx Sites
    - In first year would probably still need own deployable receiver trailer (similar to EW trailer or Peralex trailer)
  - Acquire SDR based receivers with up to 200 MHZ IWB
  - Acquire PC data capture and processing hardware solution
  - Development of processing software (bistatic Range Doppler processing, bistatic SAR processing)
  - Integrate and Test at CSIR
- Test deployment in Gauteng
  - Evaluation of test data
  - Improvements to processing
- Test deployment at identified sites
- Development of Phase 2 requirement specifications
  - Improved performance modelling of Space Segment
  - Update Transmit and Receiver segment designs based on test results
  - Develop proposal for Phase 2 (Space system proposals tend to be complex ….)



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A low-cost receiver site @ R100k ?
(in production > 1000)

Item	Cost Budget
3-4 channel receiver	< R12k
Data recorder and processor	< R13k
Data storage (cloud)	Monthly cost only
Antenna front end	R5k
RF Cabling (from front end to receivers)	R4k
Ethernet, Power cabling	R1k
User Terminal Software (NRE recovered via license per receiver)	R15k (or possibly a monthly subscription)
Enclosure + Connectors	2k
Assembly and Test	10k
Site Deployment cost (flight tickets, car rental, S+T, technician man hours)	35k

Seems feasible to achieve a site for under 100k if the support equipment is provided by Cell Tower

Exact business model will strongly determine how funds are recouped

If not, will probably be on the order of R300-500k, depending on access to deployment site and security constraints, etc

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Very first order ROI calculation

Very rough MicroSTAR Business Model				
	kR			
NRE Costs	350 000.00			
Satellite costs for constellation	320 000.00			
Months to recover costs	60.00			
Cost per site	150.00	15000	150000	1500000
Total costs		685 000.00	820 000.00	2 170 000.00
Sites		100	1000	10000
Required monthly income per site		114.17	13.67	3.62

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MicroSTAR Proof of Concept as part of Gauteng Multi-Sensor Campaign

- CSIR and several other parties currently working towards a Multi-Sensor Remote Sensing campaign
- Airborne SAR (C and L band) will be used to image
  - Crops, Dams, Urban infrastructure, Mining areas, flood risk areas, etc from December to May every two weeks
- Other sensors will also be deployed by various parties
  - Airborne and spaceborne Multi-spectral, Infrared, SAR, etc
- Ground truth will be gathered for various applications
  - Cop health, subsidence, water quality, mine activity, etc
- Provides ideal opportunity to evaluate MicroSTAR concept and its usefulness in
  - Agriculture Crop Monitoring
  - Mine subsidence and activity monitoring
  - Close to shore security applications
- Requires
  - Setup of mobile or semi-permanent sites for receivers
    - 2 or 3 channel C and/or L band
    - Ability to record data everytime a fly-over occurs
    - Improvement to the bistatic SAR processor developed at CSIR in 2016
  - Alignment with SAR Overflights
  - Evaluation post fact, to ascertain usefulness, and identify areas for improvement

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Cost of GMC PoC experiments

- Labour
  - Develop Rx Concept design
  - Procure required elements
  - Develop control software for SDR and data capture
  - Integrate and test all elements
  - Test with Airborne SAR Tx (likely on RoofSAR rail as a start)
  - Refine bistatic SAR processing software
  - Test with flyover at first test site
  - Scout for correct deployment sites (agri, mining, subsidence, urban security, etc)
  - Provide inputs to flight plans
  - Deploy and make measurements every two weeks (or as required)
  - Curate data
  - Process data into SAR imagery
  - Draw conclusions
  - Create Proof of concept report

- Running
  - SDR or other receivers bought in
    - Due to timescales will not be able to custom develop the electronics at present
    - Post PoC can consider reducing per site cost through investing in NRE for lower-cost receivers
    - Options
      - Peralex – 6 channel ADRV9009 based SDR – roughly 500k per site including data capture system
      - HJX (China) – SDRs with required capability (but probably not great tech support …) for around USD 5k per device
      - Ettus Research
        - X410 with 400 MHz BW per channel probably overkill
        - X310 with 160 MHZ BW probably sufficient
  - Data Capture unit and controller PC
  - Power supplies
  - Deployable mast / telescopic pole, or alternative
  - Site inspection costs
  - Site rental costs (if any)

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