# Introduction to:
# Moving Target Indicator Radar
# (DRAFT)

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This presentation is an informal communication intended for a limited audience comprised of attendees to the Institute for Computational and Experimental Research in Mathematics (ICERM) Semester Program on "Mathematical and Computational Challenges in Radar and Seismic Reconstruction" (September 6 - December 8, 2017).

This presentation is not intended for further distribution, dissemination, or publication, either whole or in part.

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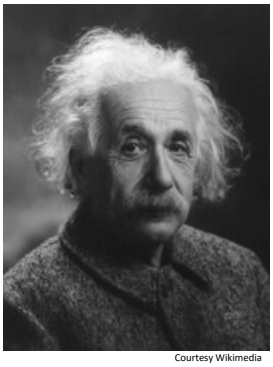

Courtesy Wikimedia

*"Nothing happens until something moves."*
*— Albert Einstein*

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## Basic Moving Target Detection (MTI) Modes

- **Ground-Moving-Target Indicator (GMTI) Radar**
  - **GMTI Wide-Area Search (GWAS)**
  - **Surface-Moving-Target Indicator (SMTI)**
  - **Dismount Moving-Target Indicator (DMTI)**
  - **Airborne Moving-Target Indicator (AMTI)**
- **Video-SAR**

All SAR images in this presentation are Courtesy of Sandia National Laboratories, Airborne ISR, unless otherwise noted.

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## Basic Concepts

One radar pulse can measure time delay to a target point

Because we know the speed of the radar wave, we can calculate a target point range from that time delay.

So… with a single radar pulse we can measure **Range**

If we collect two or more radar pulses, we can measure range changes from pulse to pulse.

So… with multiple pulses we can measure **Range Rate**

Range-rate will cause a proportional Doppler shift to the radar echo.

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## What is Doppler in SAR?

The Doppler effect (or Doppler shift) is the change in frequency of a wave (or other periodic event) for an observer moving relative to its source. It is named after the Austrian physicist Christian Doppler, who proposed it in 1842 in Prague. It is commonly heard when a vehicle sounding a siren or horn approaches, passes, and recedes from an observer.
– Wikipedia, 21 September 2017

Consider a CW pulse echo – from earlier analysis (pulses of fixed-frequency signal)

Received signal from a static range $\left|\mathbf{r}_{s,n}\right| = r_{s0}$

$$x_R(t,n,\mathbf{s}) = A_R \operatorname{rect}(\ldots)\cos\left(2\pi f_0\left(t - t_n - \frac{2}{c}r_{s0}\right)\right)$$

Received signal from a linearly changing range $\left|\mathbf{r}_{s,n}\right| = r_{s0} + v_s(t - t_0)$

$$x_R(t,n,\mathbf{s}) = A_R \operatorname{rect}(\ldots)\cos\left(2\pi f_0\left(t - t_n - \frac{2}{c}\left(r_{s0} + v_s(t - t_0)\right)\right)\right)$$

$$= A_R \operatorname{rect}(\ldots)\cos\left(2\pi f_0\left(1 - \frac{2}{c}v_s\right)(t - t_n) - \frac{4\pi f_0}{c}r_{s0} - \frac{4\pi f_0}{c}v_s(t_n - t_0)\right)$$

Time/Frequency scaling inside of a pulse

Pulse-to-pulse phase change

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Often ignored

Principal exploited effect

## What is Doppler in GMTI Radar?

A tacit assumption in GMTI is that $t_n$ increases linearly with pulse index $n$, which doesn't really care about where along the flight path those pulses emanate.

So, for SAR, a pulse-to-pulse phase change becomes a spatially-dependent phase change, i.e. a wavenumber measure.

For SAR, ultimately the velocity, and hence the times at which data are collected, is immaterial. The important factor is "where" the synthetic aperture has been sampled.

For GMTI, it is all about "when" the radar echoes are collected.

Doppler processing is typically about observing manifestations in 'slow-time'

Doppler effects within a single pulse's echo are typically ignored.

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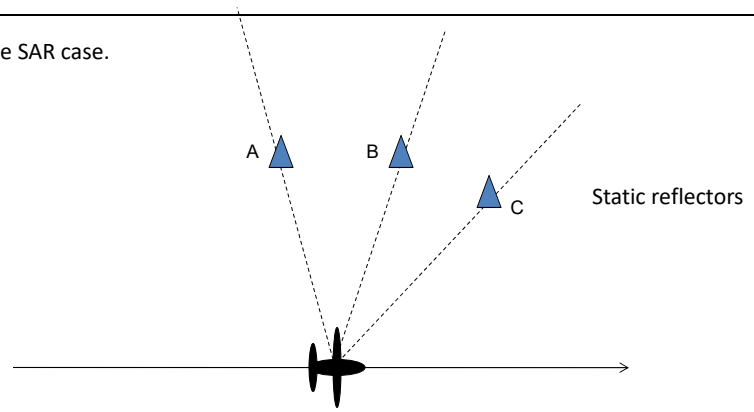
## SAR Refresh

This is the SAR case.




**Stationary targets A, B, and C are all being approached by the radar at different rates. They all have different "Range Rates".**

**A filter set for different range rates will isolate and separate the different targets.**

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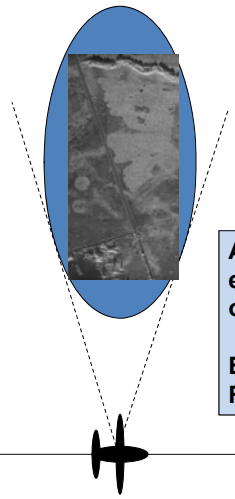
## SAR Refresh

**A SAR image is just the answer to the question "How much echo energy is there at different pairs of 'range' and 'range rate'.**

**However, the 'image' is usually restricted to range and range-rate combinations that are within the antenna beam footprint.**



All echoes are presumed to be from static reflectors

**A SAR image is an echo energy map with dimensions of Range and Range-rate…**

**Equivalently, dimensions of Range and Doppler.**

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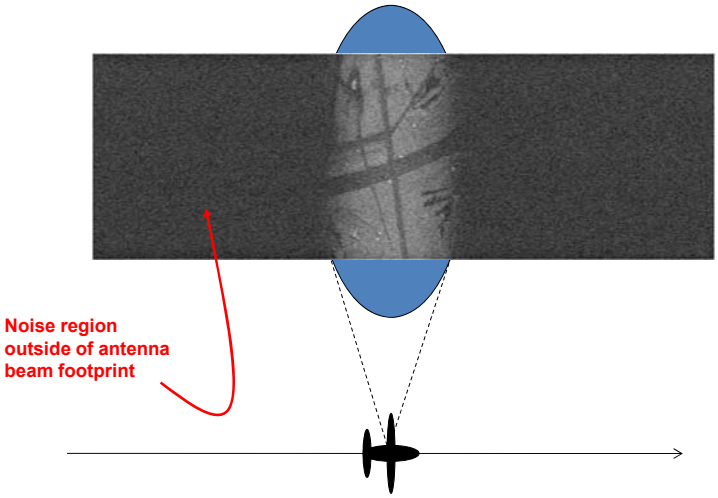
If we create a SAR image beyond the antenna footprint, then we are measuring echo energy corresponding to range and range-rate for which no echo energy should exist (assuming static reflectors).

All we should see is Noise…

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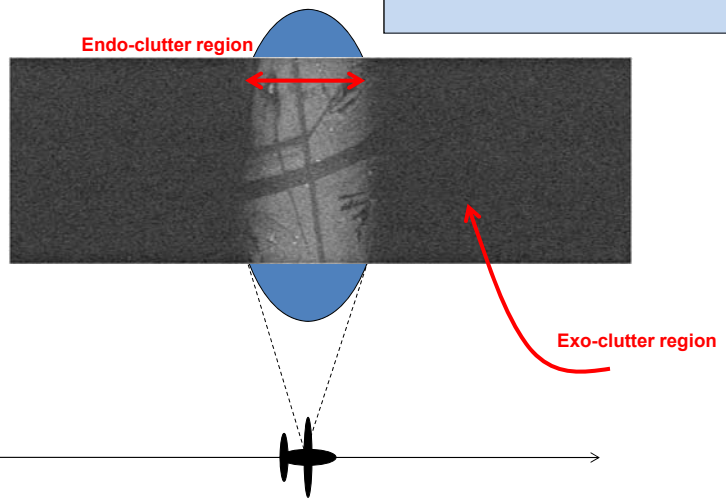
## SAR Refresh

The SAR image usually throws away the exo-clutter region before displaying some subset of the endo-clutter region.

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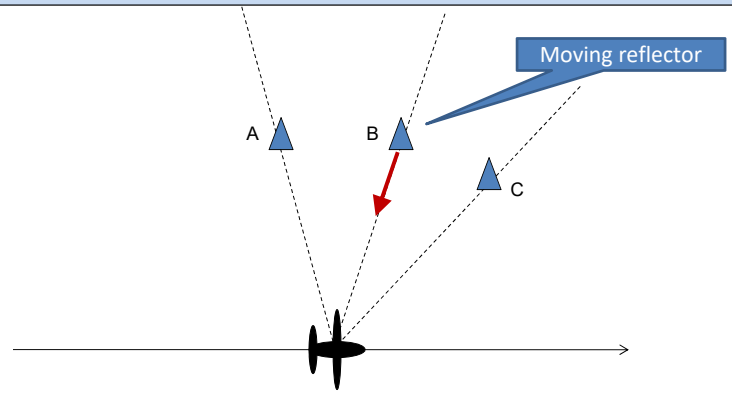
## Moving Reflectors

**If a target is moving, it is going to have a range rate that is**
**1. Due to its location,**
**-- AND--**
**2. Due to its motion.**

**The radar is going to map its energy to its range and 'total' range rate.**

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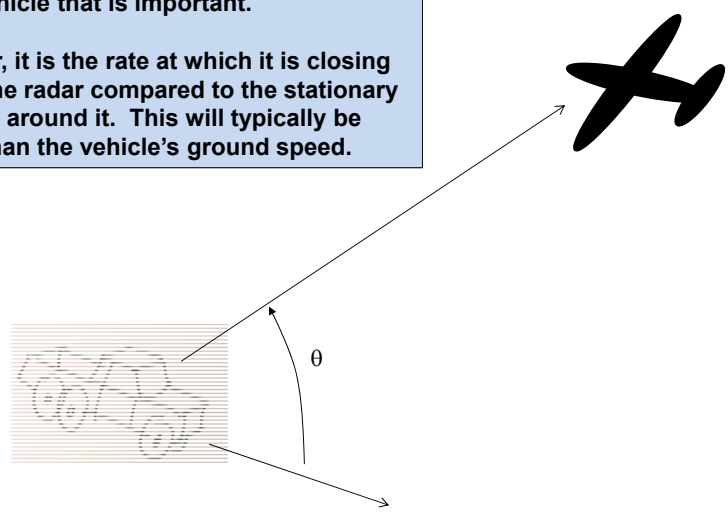
## Moving Reflectors

**Note that it is NOT the absolute speed of the vehicle that is important.**

**Rather, it is the rate at which it is closing with the radar compared to the stationary clutter around it. This will typically be less than the vehicle's ground speed.**

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## Moving Reflectors

A Moving target will have its energy mapped to a position in the SAR image that corresponds to its TOTAL range-rate.

It will be mapped to a range-rate that is different than the range-rate due just to its location. The fact that the target is moving will cause its energy to shift in the 'image'.

**A moving target's echo energy will be shifted in a Range-Doppler map.**

They will be shifted one way if velocity is towards the radar. They will be shifted the other way if the velocity is away from the radar.

The amount of shift is proportional to the velocity towards or away from the radar.

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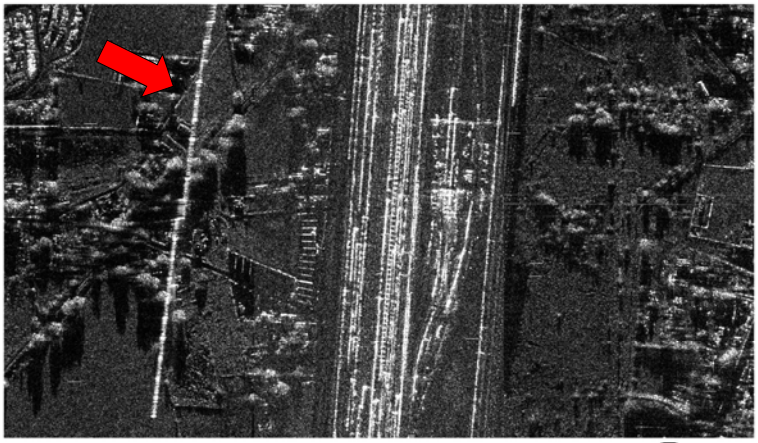
**Slow Moving Train In Albuquerque, NM**
**1 Meter Resolution – September 13, 1996**
**Range = 5 km, Depression Angle = 9.7°**



GSAT-000486-2

Note the displaced energy due to train motion.

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## Moving Reflectors

In addition, a moving reflector will not generally 'fit' the profile of a static reflector, so will often be misfocussed, even if not substantially shifted.

This manifests as 'streaks' in a SAR image – essentially misfocussed echo energy.

The pulsed nature of many radar systems also allows multiple velocities to 'alias' to the same Doppler frequency.

Consequently, MTI radars often operate at higher PRF than, say, SAR systems.

Since we are usually more interested in detection, rather than imaging, we would generally like energy to stack up into single pixels. This causes us to limit data collections to fractions of a second, else nonuniform target range-rate will cause smearing across multiple pixels, diluting their detectability – we lose target coherence.

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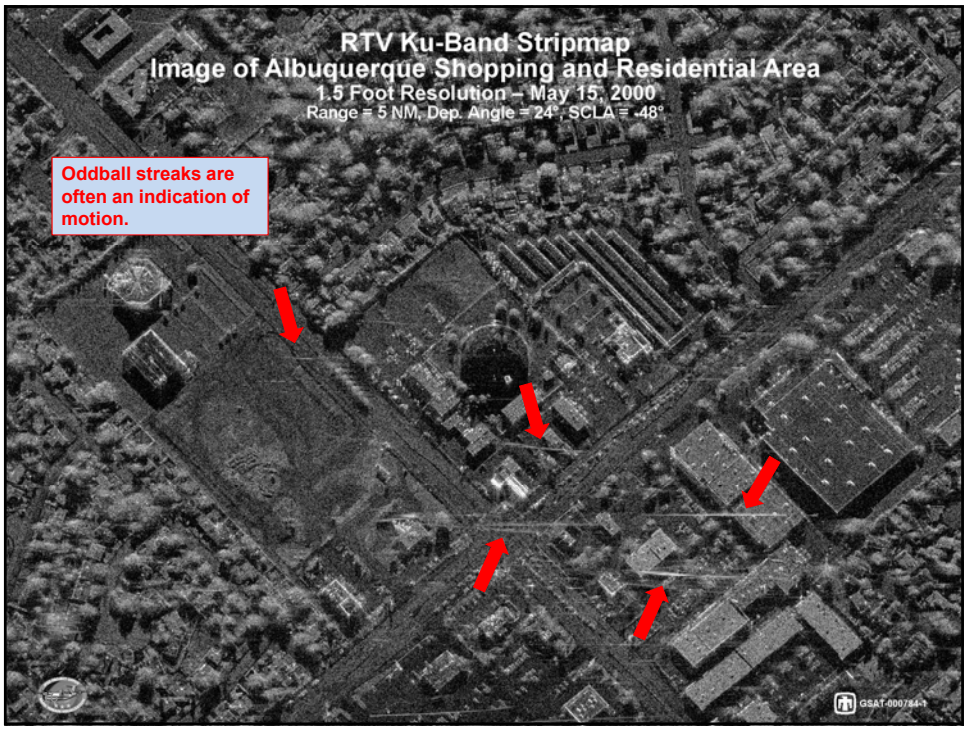

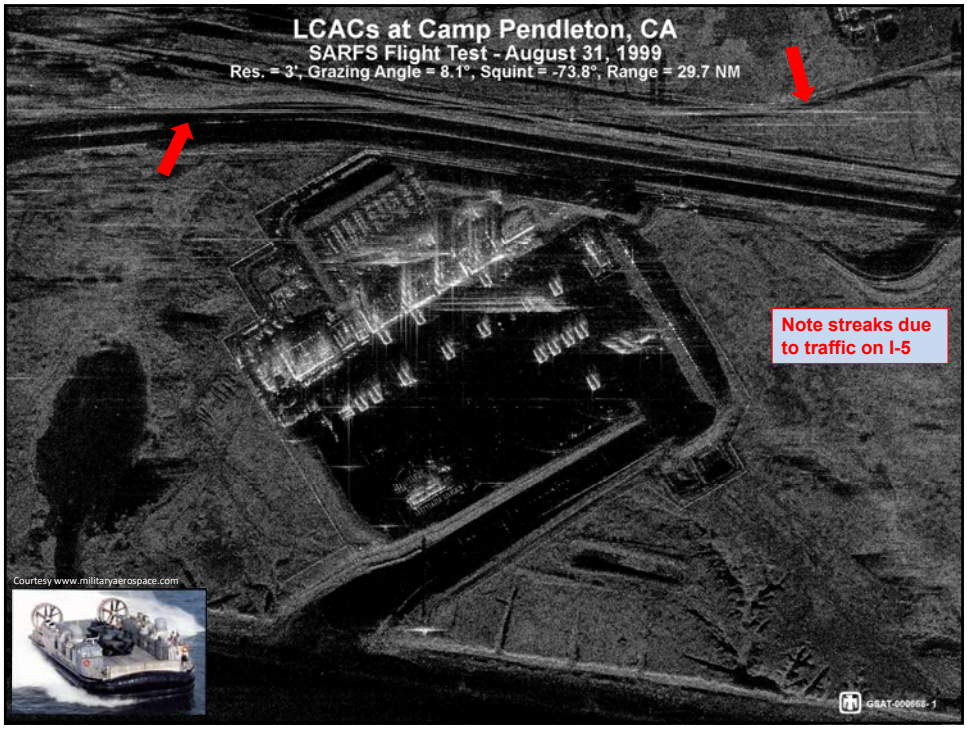


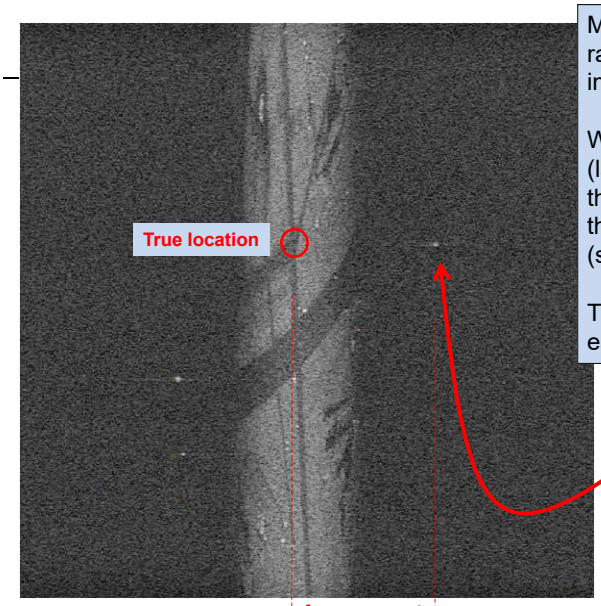


Moving objects with linear range-change are 'shifted' in Doppler.

When shifted far enough (large enough range-rate), their energy falls outside the region that stationary (static) clutter occupies.

These become relatively easy to detect.

Moving Vehicle

The vehicle is actually located in the illuminated clutter region, but its energy is shifted by its motion.

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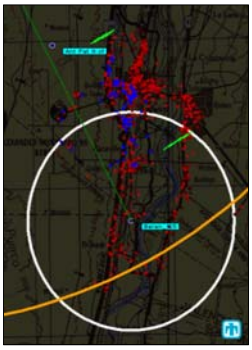
## GMTI Products

GMTI normally does not display the range-Doppler map as a data product.

Rather, the range-Doppler map is an intermediary product on the way to an automatic detection system.

The GMTI product is typically just 'detection reports' with suitable metadata (e.g. RCS estimate, closing velocity, estimated physical location, etc.).

Detections are then simply displayed on a map, sometimes color-coded, or tagged with metadata, often with tracking (time-history) information.



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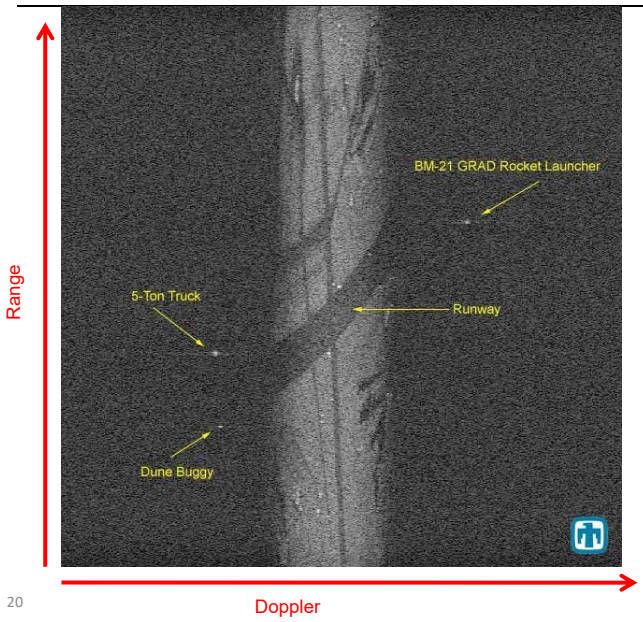
## GMTI Range-Doppler Map




**Ground Truth**

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## GMTI Range-Doppler Map

If moving targets are moving fast enough so their energy is shifted out of the antenna beam clutter (into the exo-clutter region), then we can detect them relatively easily.

But what if they are shifted only a little bit?

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## GMTI Range-Doppler Map

Is this bright spot a stationary object, or is it a moving object that has been shifted only a little bit, just not enough to push its energy into the exo-clutter region?

This suggests that to be clearly identified as a moving object, its energy must be shifted into the exo-clutter region.

It must have a minimum velocity in order to be detected – a Minimum Detectable Velocity (MDV)…

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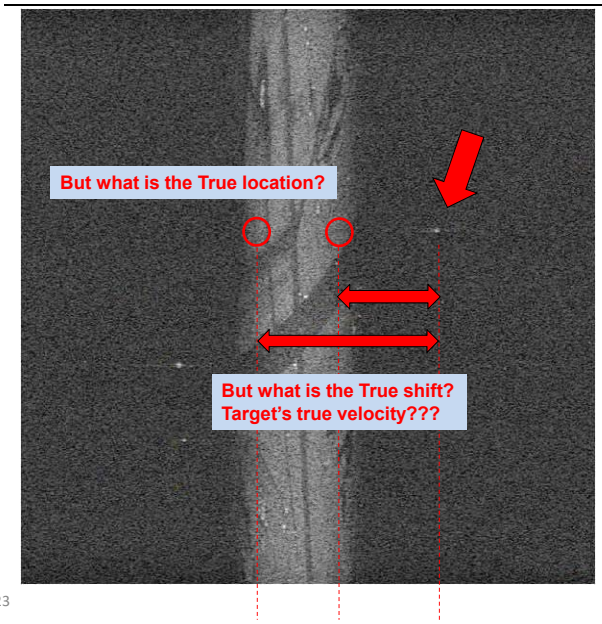
## GMTI Range-Doppler Map




If we don't know the object's true position, we can't really know its true velocity.

All we can measure is the total range-rate due to both its position AND its own speed on the ground.

So what do we do?

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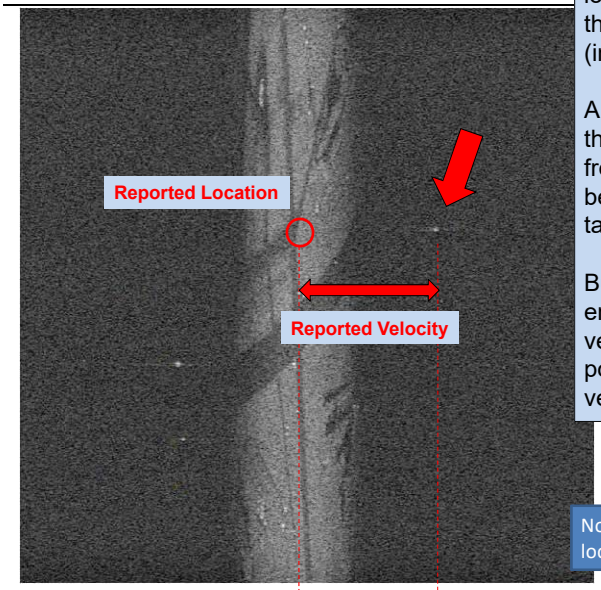
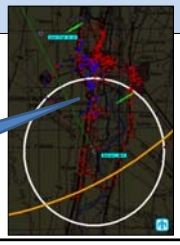
## GMTI Range-Doppler Map




Conventionally, we decide that the 'best guess' object location is in the center of the antenna beam footprint (in azimuth).

And the target velocity is the difference in range-rate from the center of the beam to the detected target's energy.

But this naturally leads to errors in the reported versus actual azimuth position and closing velocity.

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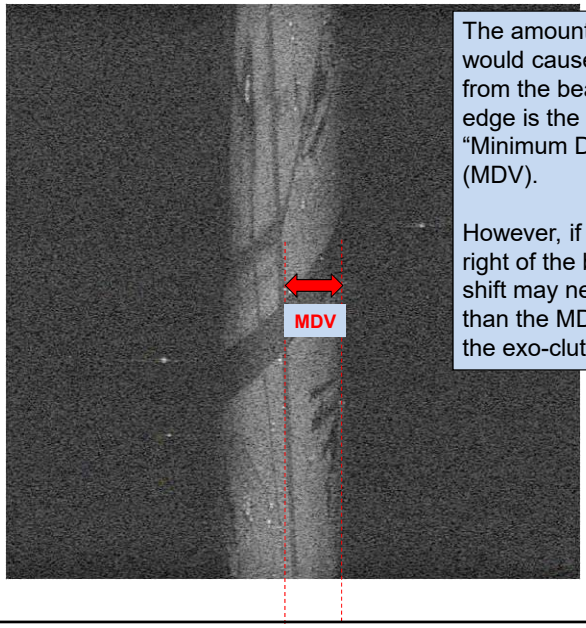
## GMTI Range-Doppler Map




The amount of target velocity that would cause a target's energy to shift from the beam center to the beam edge is the conventionally reported "Minimum Detectable Velocity" (MDV).

However, if a target is located left or right of the beam centerline, then it's shift may need to be more or less than the MDV in order to appear in the exo-clutter region.

**Targets > MDV can sometimes be missed, and Targets < MDV can sometimes be detected.**

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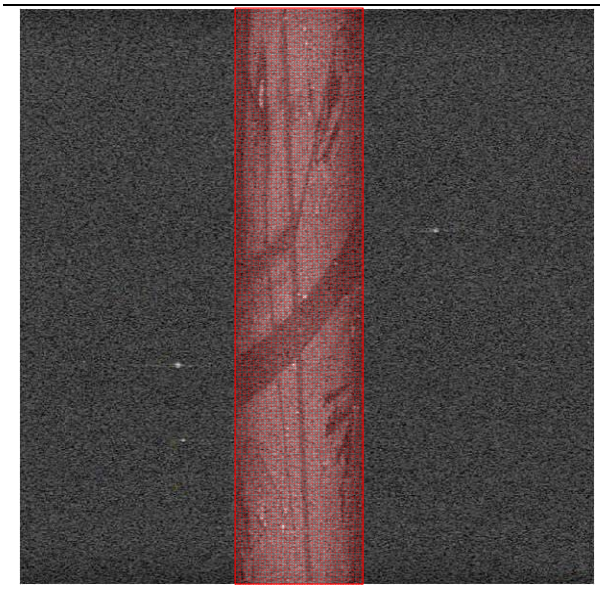
## GMTI Range-Doppler Map



In any case, the GMTI algorithm will generally 'cut out' the region within the 'MDV' limits, and not attempt to detect anything inside of this region.

Detections are limited to outside the 'endo-clutter' region.

This, of course, requires knowing where the clutter region is in range and range-rate.

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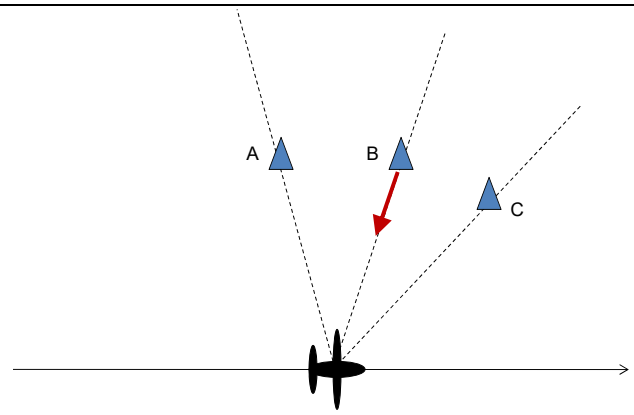
## Moving Target Doppler




The range-rate component *due to aircraft motion* depends on the aircraft velocity. This component is based solely on position, and is true for all objects, including stationary objects, i.e. clutter…

The range-rate component *due to target motion* does NOT depend on the aircraft velocity.

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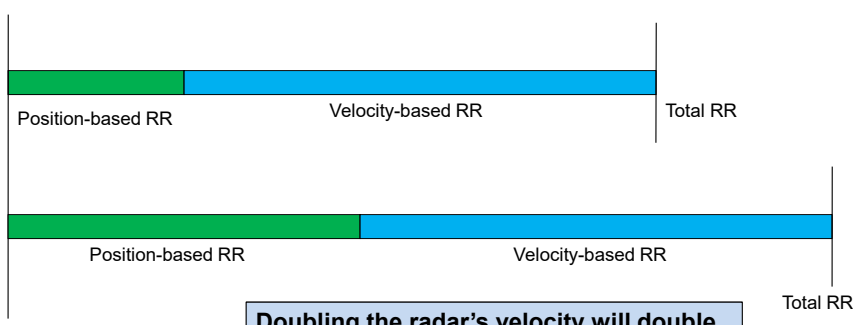
## Moving Target Doppler

So… The faster the radar flies, the greater is the range-rate (Doppler) spread due to position…

Stationary clutter gets wider in the range-Doppler map

But moving objects do not shift proportionately.




**Doubling the radar's velocity will double the clutter width, but not double the shift of a moving object.**

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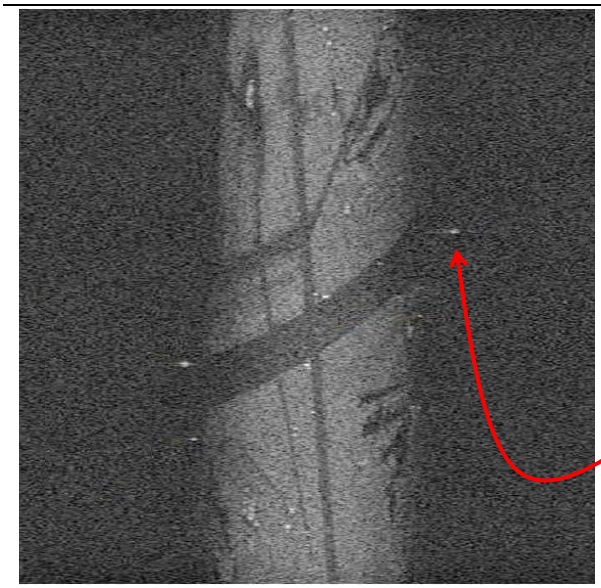
## Moving Target Doppler



If the radar flies faster, the clutter region widens, but the vehicle Doppler shift due to its own motion is unchanged.

We start to lose MDV (MDV gets bigger).

**Note that the vehicle energy is closer to the clutter edge.**

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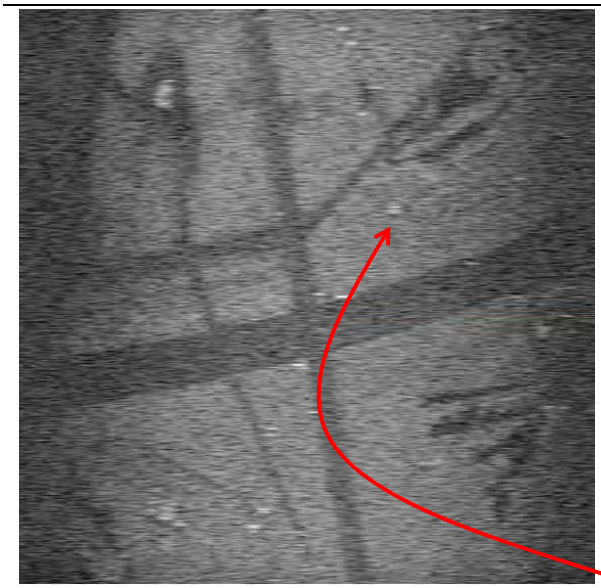
## Moving Target Doppler



At very high velocities, the clutter takes up all the Doppler bandwidth.

There is little or no exo-clutter region.

All movers are inside the clutter region and therefore undetectable by the simple means.

This is typical of fast jet aircraft.

**Is this bright dot a mover that is shifted just a little bit, or is it a stationary object?**

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## Detectable Velocity

So… We like narrow clutter regions so that we can have a low MDV.

We can make the clutter region narrower again by using a narrower beamwidth antenna. This means an antenna with larger azimuth dimension; a bigger antenna…

We can also make the clutter region narrower by flying slower. We can mimic this by pointing the antenna closer to the nose of the aircraft.

Ideally, the radar is stationary, i.e. hovering

Courtesy Lockheed Martin

**In this manner we can detect some rather slow-moving targets, like people walking (sometimes called "dismounts").**

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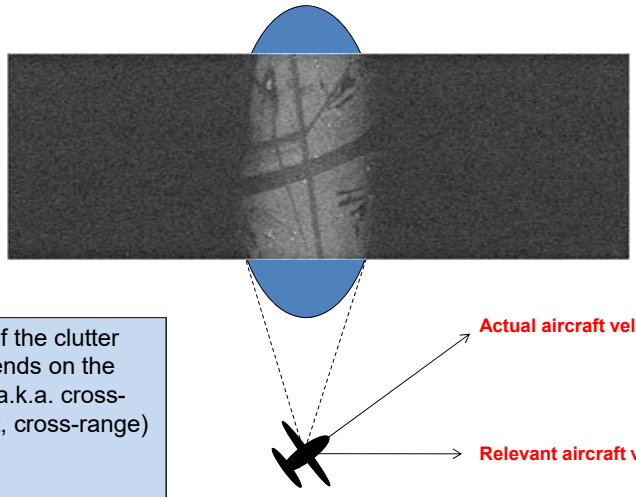
## Detectable Velocity




The width of the clutter region depends on the tangential (a.k.a. cross-line-of-sight, cross-range) velocity.

The velocity component in the cross-range direction

MDV is lowest straight-ahead, or straight-behind the aircraft heading.

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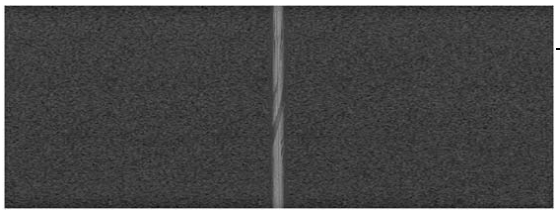
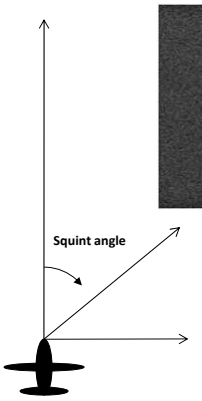
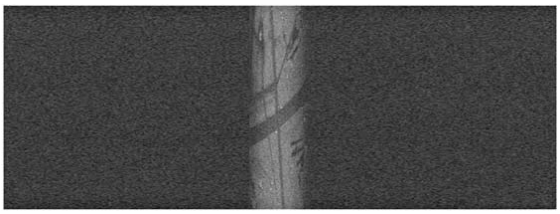
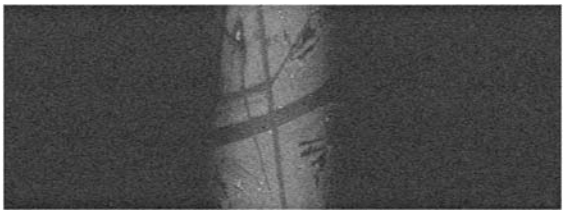
## Detectable Velocity







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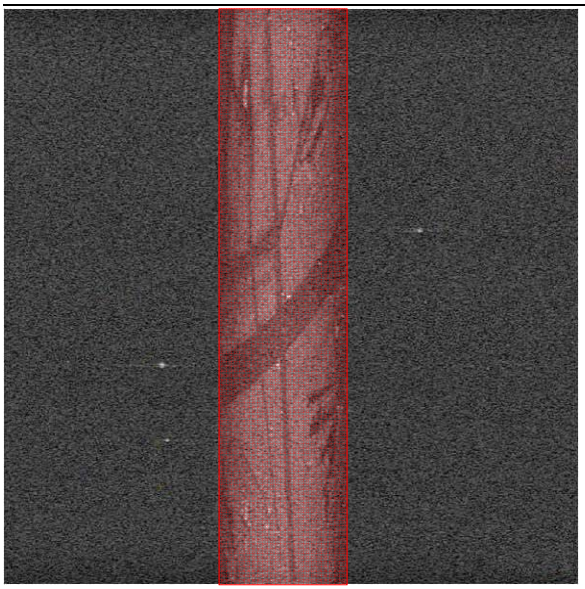
## Detectable Velocity



Determining the exclusion region for detections depends on knowing where the clutter region is in range and Doppler.

BUT…

The range and range-rate depends on the radar's viewing geometry… which in turns depends on the scene topography…

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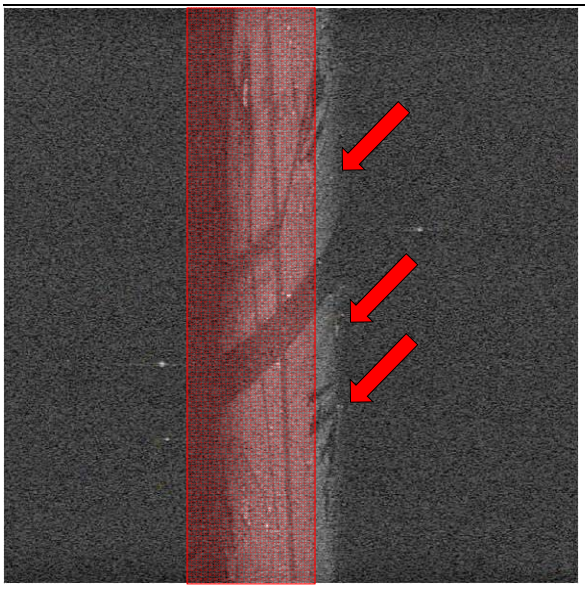
## Detectable Velocity



Expected clutter region

If we get the clutter exclusion region wrong, then we will detect as a moving target some echo energy that is really from a stationary clutter object.

-- increased False Alarms

Or perhaps miss a valid moving target.

-- decreased Probability of Detection

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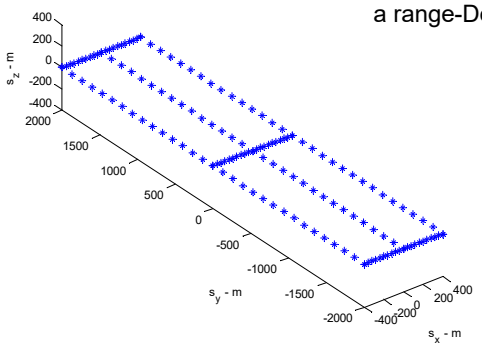
## Topography Effects

Suppose we have an array of stationary corner reflectors on the ground.

What would this clutter look like in a range-Doppler map?

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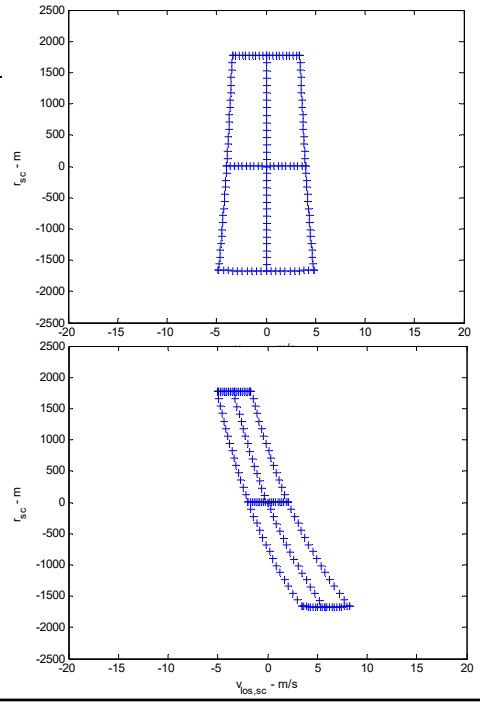
## Topography Effects

At broadside, the array looks essentially vertical, although with some distortion that shrinks in azimuth at farther ranges.

This is due to the fact that Range-rate, or Doppler is an angle phenomenon, and our ground-truth has constant linear distance dimensions.

At squint angles, the clutter is warped to a non-vertical band.

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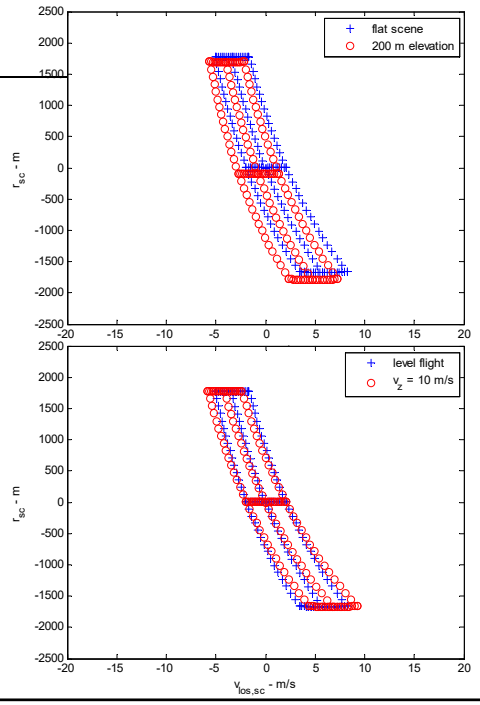
## Topography Effects

If the scene is at a different altitude than expected, the clutter band will shift in both range AND range-rate (Doppler).

A vertical velocity component (radar climbing or descending) will also warp the clutter band.

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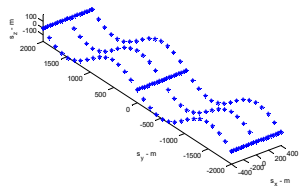
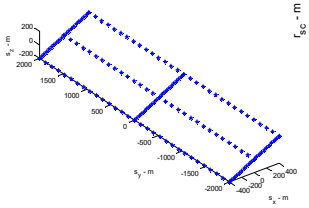
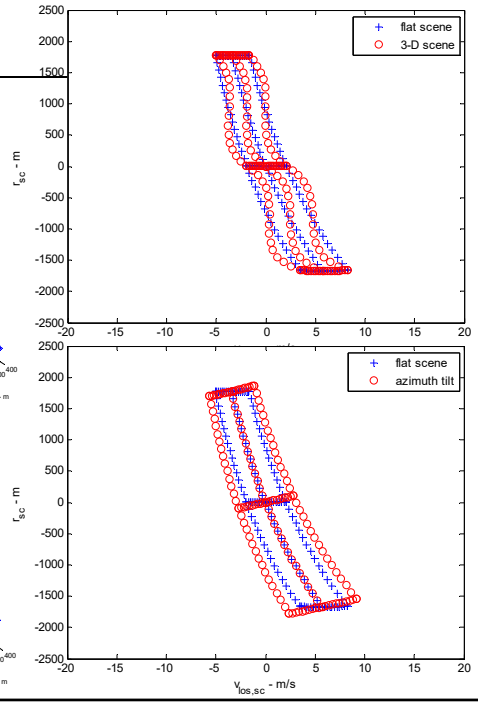
## Topography Effects

If the scene has non-level topography, then the range-Doppler map will reflect this with corresponding range-rate displacements.



A scene that is tilted in cross-range will exhibit a broadening or narrowing of the clutter band.



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## Topography Effects

**Bottom Line:**

**To minimize False Alarms, and maximize detections, the radar needs to account for topography when deciding where the clutter band is.**

**The radar needs access to DTED data – especially in mountains.**

**It's all about accounting for "layover"**

DTED = Digital Terrain Elevation Data

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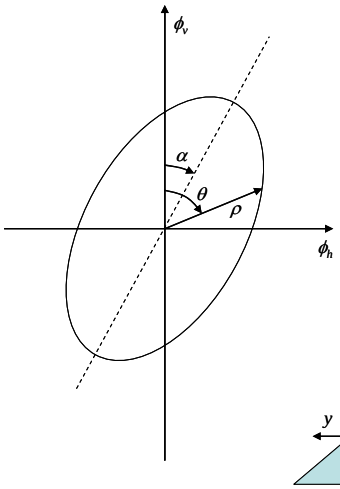
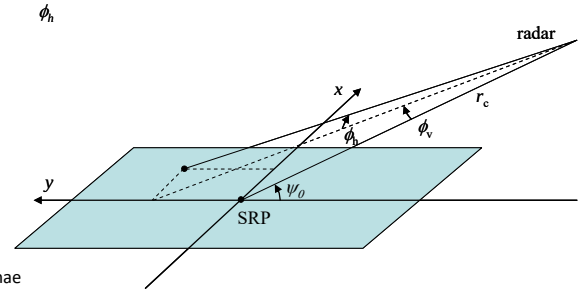
# Antenna Twist




What if the antenna beam is twisted about its axis?

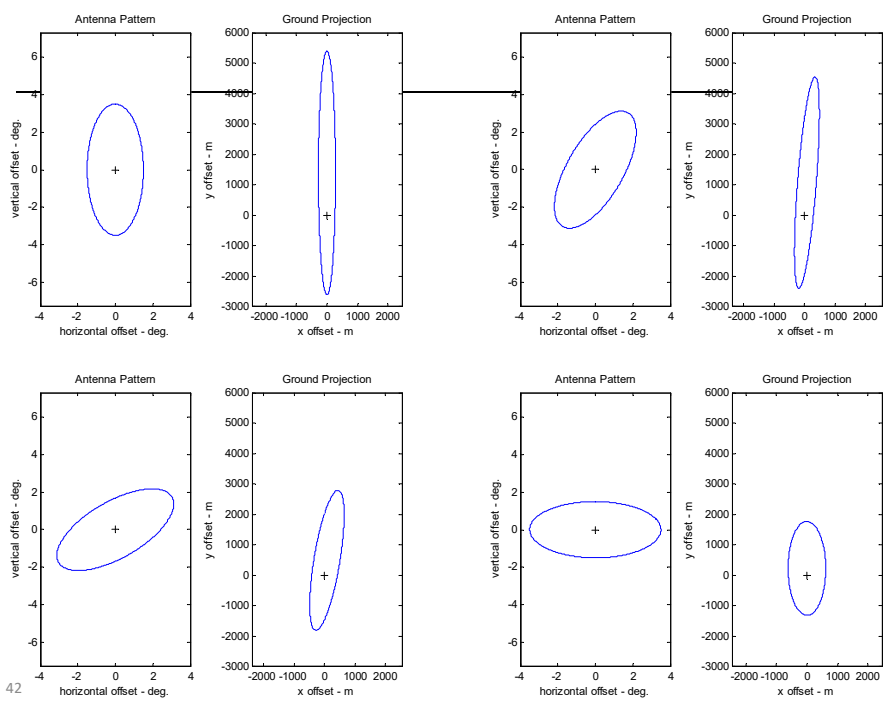
If the beam is twisted, the antenna beam footprint will be different than expected…

and the clutter band will be different than expected…




An issue for 2-axis gimballed antennae

41

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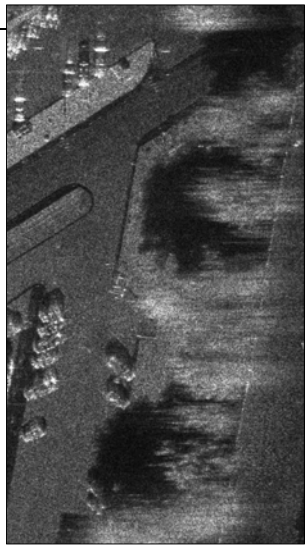
## Clutter Motion

Sometimes stationary clutter isn't all that stationary

up to 0.32 m/s for wooded hills with 40 kt wind,
up to 1.1 m/s for sea echoes,
up to 1.2 m/s for chaff in 25 kt wind, and
up to 4.0 m/s for rain clouds.



Likely to have more false alarms on windy days

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## Basic Multi-Channel DMTI/GMTI

**Reducing MDV**

Sometimes we want to detect some very slow-moving targets, like people (or "dismounts") walking.

These have small RCS, 0 dBsm to -10 dBsm,

and move with low velocities, less than 1 m/s.

Dismount Moving Target Indicator (DMTI) radar.

DMTI is just GMTI for people targets…

With a single-beam antenna, we would need some combination of
1. Large antenna
2. Slow radar velocity
3. Limited to forward or aft squint angles

Sometimes we need "more"

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*"If a problem can't be solved, enlarge it."*
*-- Dwight D. Eisenhower*

Dwight D. Eisenhower Presidential Library and Museum, National Archives (63-92)

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## Reducing MDV

An alternative is to use a more exotic GMTI scheme.

We essentially need to separate or discriminate the energy of the stationary clutter from the energy of the slow-moving vehicle or dismount.

This requires another degree of freedom, that is, another source of information. This is accomplished with a multi-phase-center (or multi-beam) antenna and a multi-channel radar system. This is a more complex hardware and software solution.

A new dimension to the data

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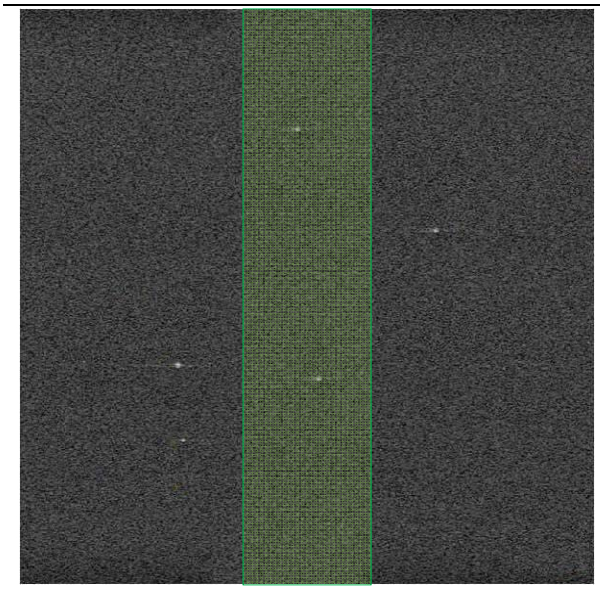
## Clutter Cancellation/Suppression



Clutter band region

If clutter is sufficiently cancelled or suppressed (filtered), the moving targets become 'visible' again.

These techniques are generically called "Endo-clutter" GMTI techniques.

Such systems are typical for fast-moving platforms, such as J-STARS, GlobalHawk, and orbital GMTI concepts.

These systems are harder to design, build, calibrate, etc.

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## Clutter Cancellation/Suppression

For example, we can take two separate SAR images of the same scene, but at slightly different times, but equal in all other respects.

Whatever is different between the two images must be due to something that has moved, even if by only a fraction of a wavelength. [change detection]

The basic idea for detecting moving targets in the endo-clutter region is to:

Make two (or more) range-Doppler maps
- From essentially the same place in space (along same flight path)
- But at slightly different times (i.e. front-half and back-half of antenna)

Complex pixels that 'match' are identified as '**clutter**'. By mapping the "mis-match" in the range-Doppler map, we have essentially cancelled, or suppressed, stationary (static) clutter.

Pixels that 'don't match' in the range-Doppler map are identified as '**moving objects**'.

Having the second range-Doppler map yields an extra degree of freedom - an extra amount of information to allow separating stationary clutter from moving targets.

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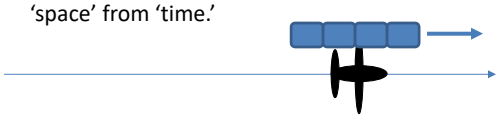
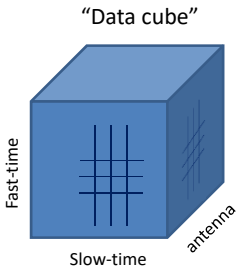
## Clutter Cancellation/Suppression

All practical GMTI processing algorithms have in common the notion that we have 'multiple' simultaneous perspectives (antennas) along with multiple time history of pulses for each of them.

In this manner, we can somewhat decouple 'space' from 'time.'






This, of course, means we need to process across both dimensions of 'space' and 'time.'

**Space-Time Processing**

Gives us an angle measure

Gives us a Doppler measure

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## Clutter Cancellation/Suppression

**There are a variety of processing algorithms for multiple antenna phase centers, or multiple antenna beams.**

**These go by various names, like**

1. **Displaced Phase Center Antenna (DPCA)**
2. **Along Track Interferometry (ATI)**
3. **Space-Time Adaptive Processing (STAP)**

**All are related and essentially try to do the same thing; look for reflectors that do not behave as static clutter.**

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## Displaced Phase Center Antenna (DPCA)

**Background:** Consider the sum of two echo signals, after demodulation, one that is at a constant range, and one that is at a range that is changing with pulse number.

$$x_R(n) = \cos\left(-\frac{4\pi f_0}{c} r_{s0}\right) + \cos\left(-\frac{4\pi f_0}{c} r_{s1} - \frac{4\pi f_0}{c} v_{s1}(t_n - t_0)\right)$$

Stationary target

Moving target

Target velocity

Now take the difference between adjacent pulses, spaced $T_p$ apart in time.

$$x_R(n) - x_R(n-1) \approx \frac{4\pi f_0}{c} v_{s1} T_p \sin\left(-\frac{4\pi f_0}{c} r_{s1} - \frac{4\pi f_0}{c} v_{s1}(t_n - t_0)\right)$$

The stationary target has been cancelled, but the moving target, by virtue of its velocity, passes this simple filter.

**Single-delay canceller.**

More elaborate schemes exist

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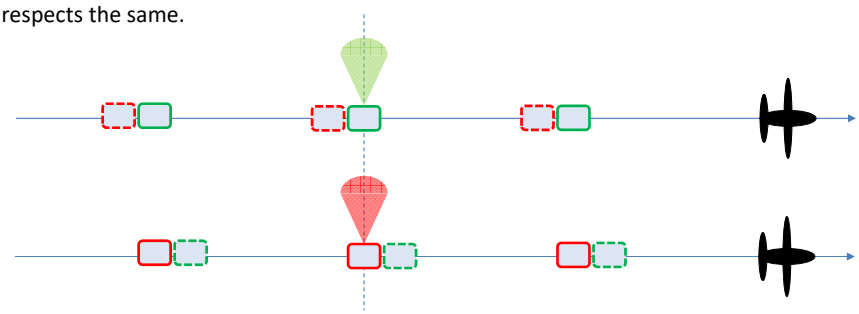
## Displaced Phase Center Antenna (DPCA)

A pair of antennae are arranged to follow the same flight path exactly, and are otherwise in all respects the same.



As a pair of antennae fly past a target scene, the fore antenna interrogates the scene, followed by the aft antenna interrogating the same scene from the same place in space, but delayed in time.

The echo from the aft antenna at pulse $n$+1 are subtracted from the echo of the fore antenna at pulse $n$ to yield a stationary-clutter cancelled output.

This is done for every pixel in a range-Doppler map.

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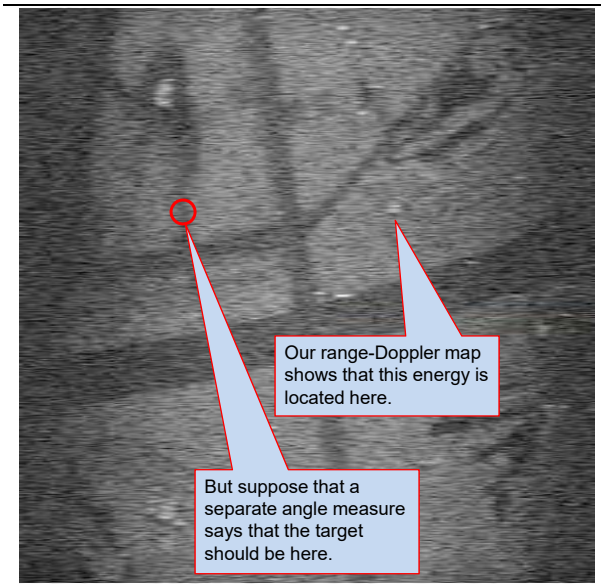
## Along Track Interferometry (ATI)




Alternatively, suppose that we had a separate angle measure for each and every pixel in a range-Doppler map.

If the separate angle measure shows the direction of the echo is different than to where it shows up in the range-Doppler map, then the target's energy must have been shifted due to its motion.

So this pixel's echo energy must be from a slow mover.

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## Monopulse Antennae

Courtesy NY Daily News

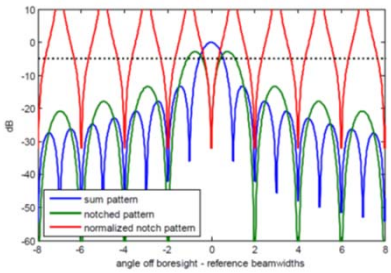
Monopulse techniques are derived from early tracking radars, where the ratio of separate beams were used directly to drive the pointing of an antenna to keep it centered onto a target.

"Monopulse" refers to the ability to determine Direction of Arrival (DOA) using "nulls" generated from multiple beams with a single pulse.

Courtesy BAE Systems

An inherent truth with filters and antenna beams is that "nulls" are much sharper (more localized) than peaks.

-- better suited for DOA measurements




Uniformly illuminated aperture

- blue = sum pattern
- green = left – right

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## How to measure angle: **Amplitude Monopulse Antenna**

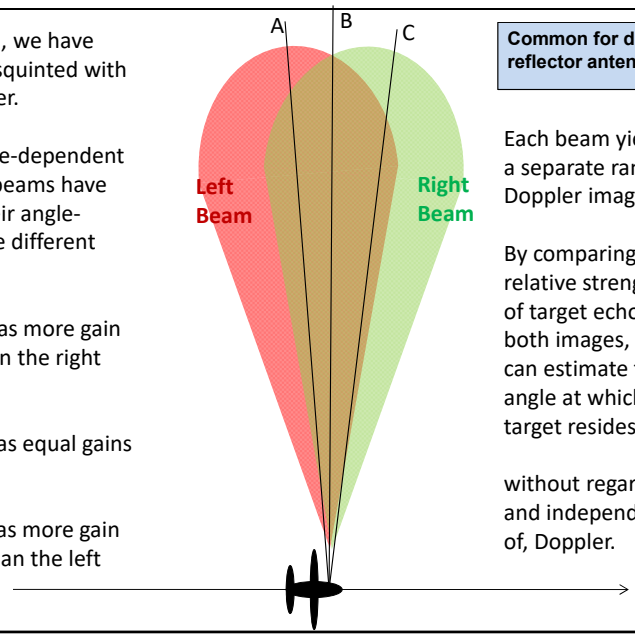
In this configuration, we have two beams slightly squinted with respect to each other.

Each beam has angle-dependent gain, but since the beams have different squint, their angle-dependent gains are different from each other.

Target direction A has more gain in the left beam than the right beam.

Target direction B has equal gains in both beams.

Target direction C has more gain in the right beam than the left beam.




**Common for dish reflector antennae.**

Each beam yields a separate range-Doppler image.

By comparing the relative strength of target echo in both images, we can estimate the angle at which the target resides…

without regard for, and independent of, Doppler.

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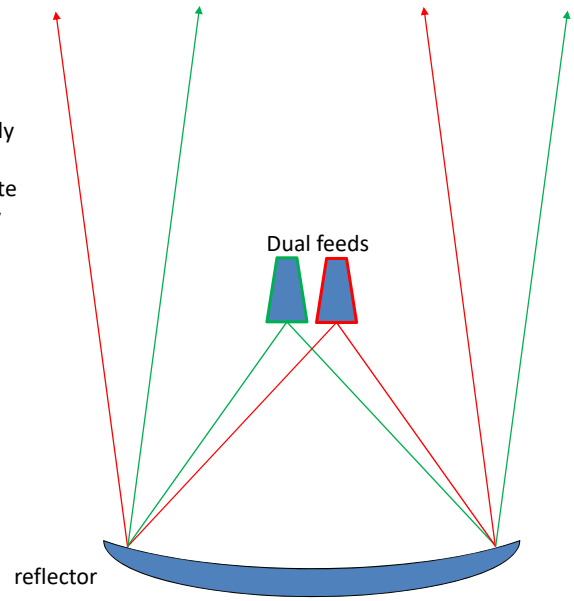
## Amplitude Monopulse Antenna

Dual-Feed Reflector Antenna

By using two feeds, each slightly offset from the focal point of a reflector antenna, we can create the two beams with effectively common origin, but slightly different squint angles.

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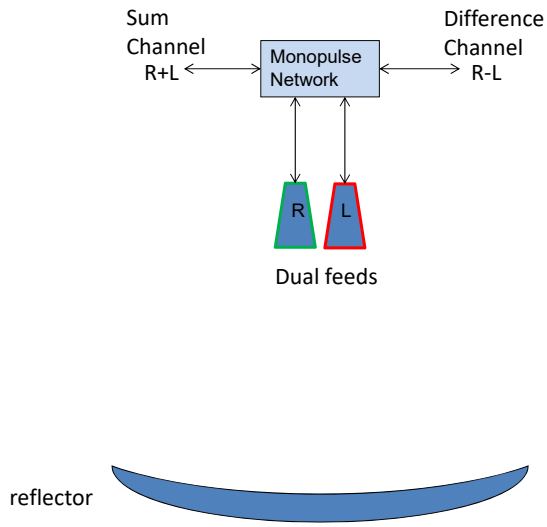
## Amplitude Monopulse Antenna

For signal processing convenience, frequently instead of left and right channels, the radar receives sum and difference channels.

The monopulse network is bi-directional.

The transmitted signal is usually fed to the sum channel, so that it is applied equally to both feeds,

Has some advantages when dealing with processing channel imbalances.

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## How to measure angle: **Phase Monopulse Antenna**

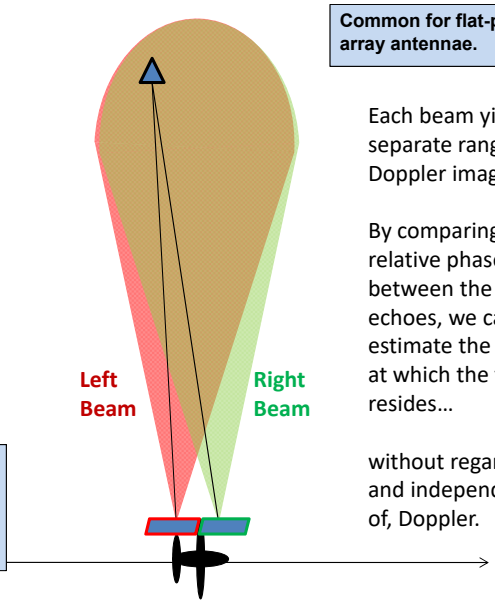
In this configuration, we have two beams with slightly different phase center locations, but otherwise squinted the same.

Each beam has slightly different range to target, manifesting as a slight phase-difference in the respective target echoes.

The phase difference depends on how left or right the target is with respect to the boresight direction.

The choice between amplitude versus phase monopulse is more about convenience for a particular antenna technology (e.g. dish vs. flat panel array). Otherwise there is no real advantage of one over the other for a given antenna size constraint.

**Common for flat-panel array antennae.**




Each beam yields a separate range-Doppler image.

By comparing the relative phase between the echoes, we can estimate the angle at which the target resides…

without regard for, and independent of, Doppler.

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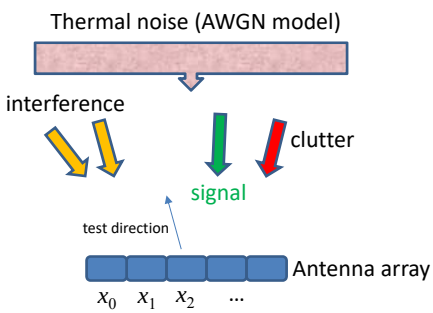
## Space-Time Adaptive Processing (STAP)

For each and every range-Doppler combination, we want to examine the data over the physical antenna array to see if a signal can be detected in the presence of noise and whatever interference/clutter may exist.

We wish our filter to 'adapt' to the RF environment, to maximize our ability to detect the signal, with minimum expected mean-squared-error.




$\mathbf{w}_{opt} = \left(\mathbf{v}_s^H \mathbf{R}_{\mathbf{nn}}^{-1} \mathbf{v}_s\right)^{-1} \mathbf{R}_{\mathbf{nn}}^{-1} \mathbf{v}_s =$ optimal weights

where $\mathbf{R}_{\mathbf{nn}} =$ Covariance matrix of everything undesired

$\mathbf{v}_s =$ Steering vector for desired look direction

$y = \mathbf{w}_{opt}^H \mathbf{x} =$ Optimally filtered output

"Adaptive beamforming"

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## Space-Time Adaptive Processing (STAP)

The performance of STAP is highly dependent on accurate estimation of the covariance matrix $\mathbf{R}_{\mathbf{nn}}$

Hard part

This is especially difficult due to
1. Limited data with which to estimate
2. Nonhomogeneous clutter from which to estimate

These difficulties lead to suboptimal filters, which lead to excessive false alarms and reduced detection probabilities.

Schemes to deal with these difficulties abound.

More recently, there has been some success in developing the optimal filter without overtly calculating the covariance matrix, usually involving some iterative adaptation.

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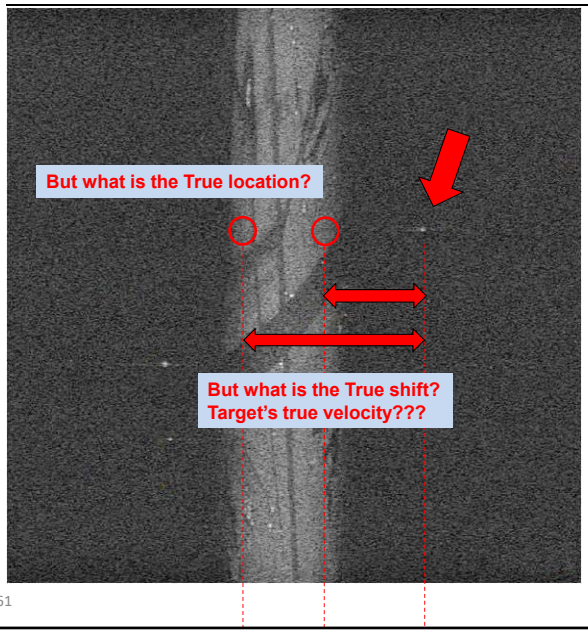
## Moving Target Geolocation




Actually, multiple antenna beams allows separating position information from velocity information.

We can now resolve this ambiguity as well.

Consequently, multiple antenna beams allow more accurate azimuth position information.

Two or more antennas allow improved exo-clutter Direction of Arrival (DOA) measurement.

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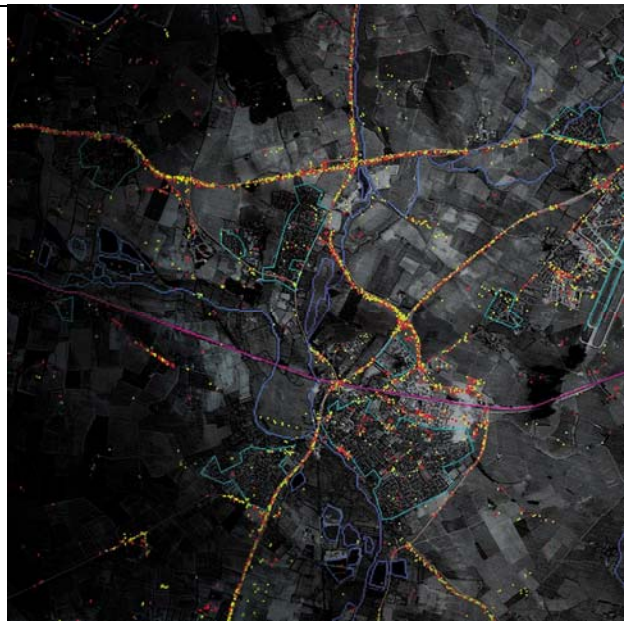
## Moving Target Geolocation

Clearly, we desire to know accurately just where the moving targets are located; placing them in their correct location, and on their correct path.

Courtesy Wikimedia.org



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## How many antenna beams are enough?

Fundamentally, $N$ samples can produce $N$-1 independent nulls.

In addition, we can view the problem of determining DOA as one of optimal null-steering.

Courtesy GlobalSecurity.org

J-STARS – 3 phase centers

Photo by Alan Radecki

NGC VADER – 4 phase centers

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**One phase center** can "detect" an exo-clutter target,
but does a poor job of DOA; limits DOA to "within the antenna beam."

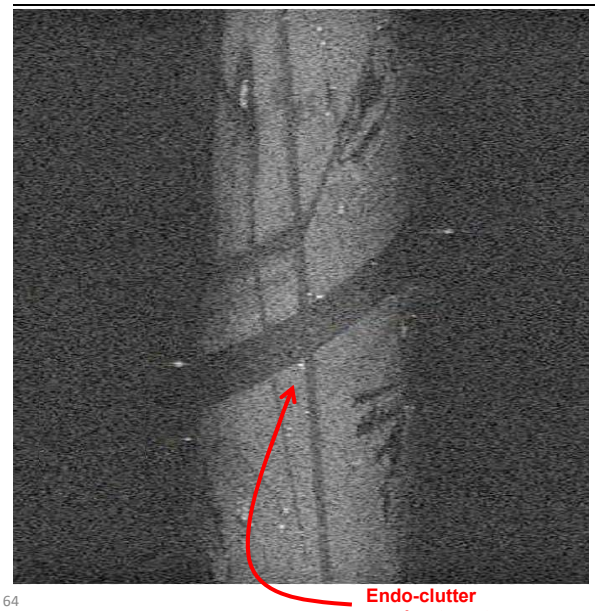
**Two phase centers** allow "detecting" an endo-clutter target,
but DOA estimation for a single exo-clutter target.

**Three phase centers** allow DOA estimation for an endo-clutter target.

**Additional phase centers** allow nulling additional interfering signals; one additional interfering signal for each additional phase center.

Phase centers are assumed to be linear in azimuth

## How many antenna beams are enough?




For moving vehicles within the clutter band, any one pixel is a sum of both moving target energy, and stationary clutter energy.

This messes up the DOA measurement. While two antenna beams allows detection inside the clutter, target location is still inaccurate inside the clutter.

To facilitate good moving target location accuracy inside the clutter, we need three or more antenna phase centers (beams)

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## Target Elevation

More recently, there is an increasing need to distinguish slow-moving targets "on the ground" from slow-moving targets "just above the ground."

This will require an ability to measure target elevation, likely via elevation DOA techniques similar to IFSAR/InSAR.

Also helps with topography effects.

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## Target Tracking

Courtesy Wikimedia.org

It is often not sufficient to know the location of all moving targets.

In particular, we often want to follow a *particular* moving target,

or understand from where, and/or to where, those targets are moving, i.e. a *time-history*.

This means 'tracking' those targets.

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## Nonlinear Motion

Not all motion is translational.

Sometimes motion may be rotation, vibration, etc.

YouTube video courtesy Sterling Davis Photo

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## Moving Features

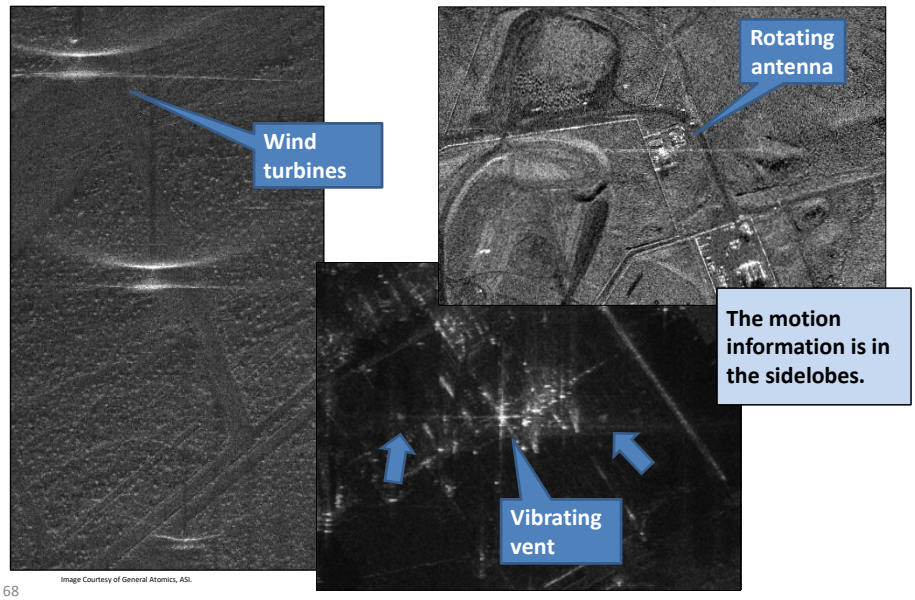


Image Courtesy of General Atomics, ASI.

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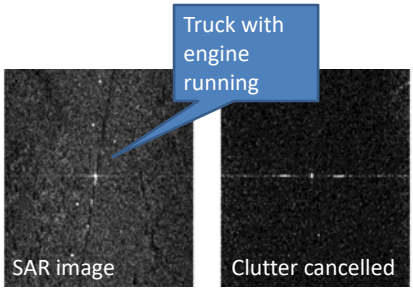
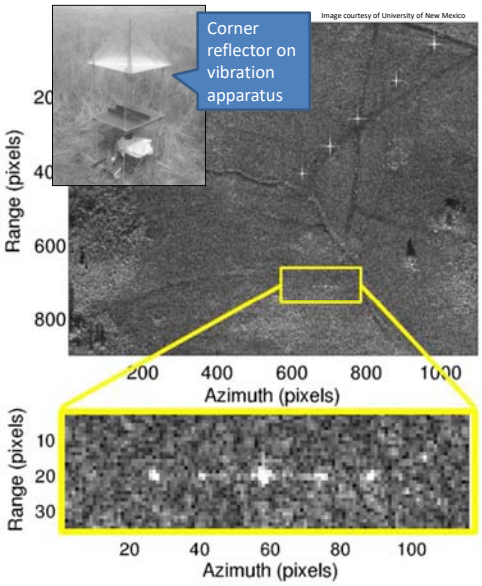
## Moving Features – Vibration & Rotation

**Vibration and rotation involve alternating positive and negative line-of-sight velocities during a synthetic aperture.**

**These will tend to throw Doppler sidelobes in both directions.**

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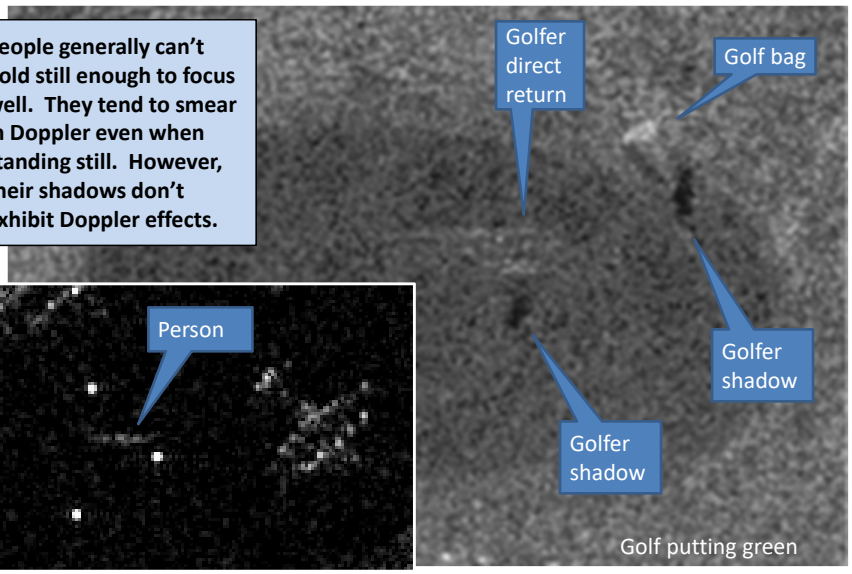
## Moving Features – People

**People generally can't hold still enough to focus well. They tend to smear in Doppler even when standing still. However, their shadows don't exhibit Doppler effects.**

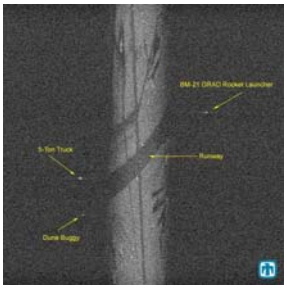


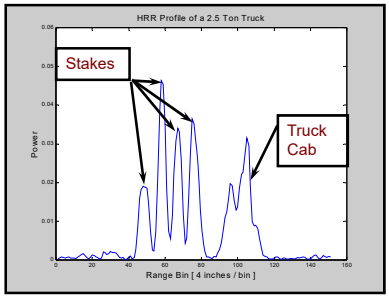



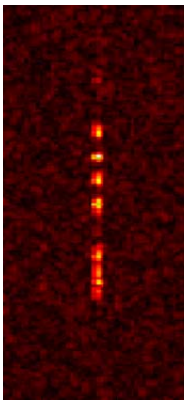

70 Ku-band Ka-band

## High-Range-Resolution (HRR) GMTI

The unique ultra-fine range resolution allows High-Range-Resolution (HRR) Ground Moving Target Indication (GMTI). This allows exploiting vehicles' unique range profiles for moving target discrimination and identification.



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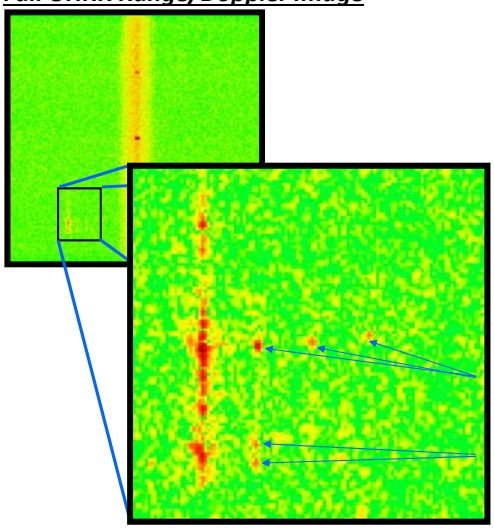
## UHRR Micro-Doppler Signatures

***Full UHRR Range/Doppler Image***



***Photograph of 2.5 Ton Truck***

***Radar returns from front axle lug nuts***

***Radar returns from dual rear axles***

***UHRR Signature of 2.5 Ton Truck (4 inch range resolution)***

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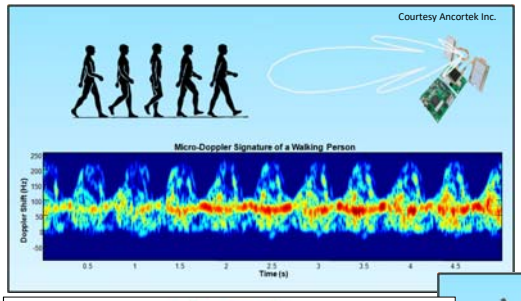
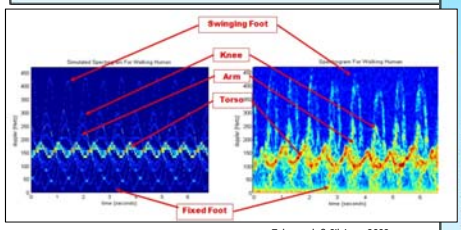
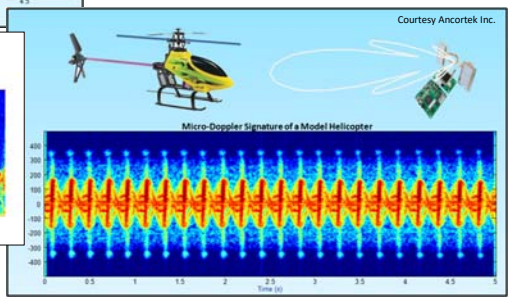
## Micro-Doppler Motion Analysis




Micro-Doppler analysis allows assessment of articulated motion, leading to classification and identification of target classes, activities, and state-of-health.




Tahmoush & Silvious, 2009

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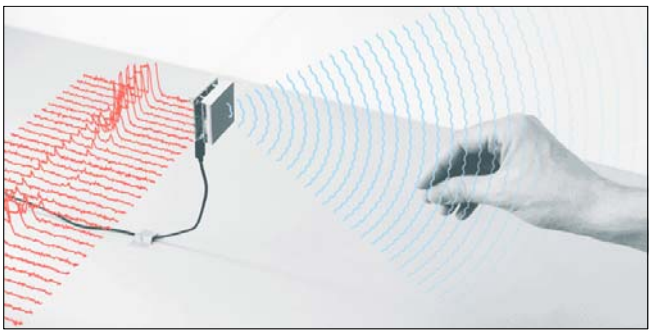
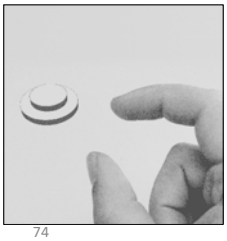
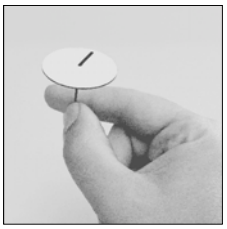
## Motion Analysis

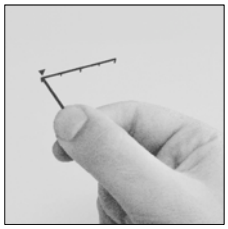


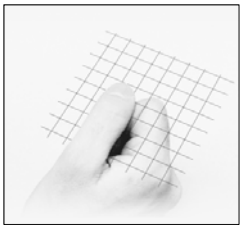
Google Project Soli

Virtual Tool Gestures









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Images courtesy Google

## VideoSAR

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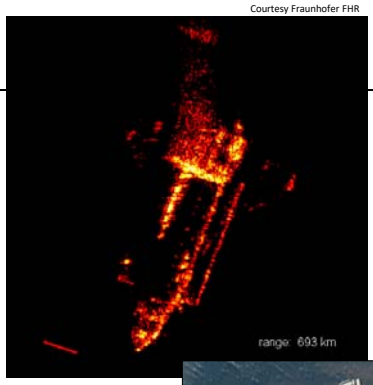
## Inverse-SAR (ISAR)

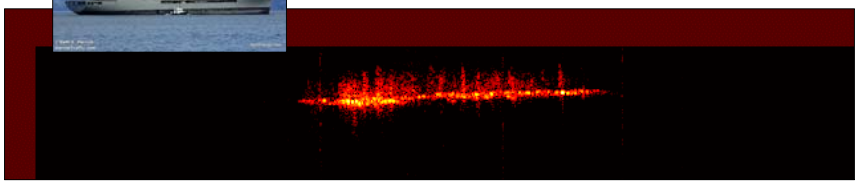
Courtesy Fraunhofer FHR




It is possible to image moving targets.

This involves estimating and compensating for its motion, and essentially rendering only its micro-Doppler energy.

Works best if there is minimal background clutter, as with ships, aircraft, spacecraft, etc. – but much more difficult for land vehicles, especially slow vehicles.



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Courtesy General Atomics ASI, Inc.

## Select References

- **Performance Limits for Exo-Clutter Ground Moving Target Indicator (GMTI) Radar**
  - **Sandia National Laboratories Report SAND2010-5844**

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