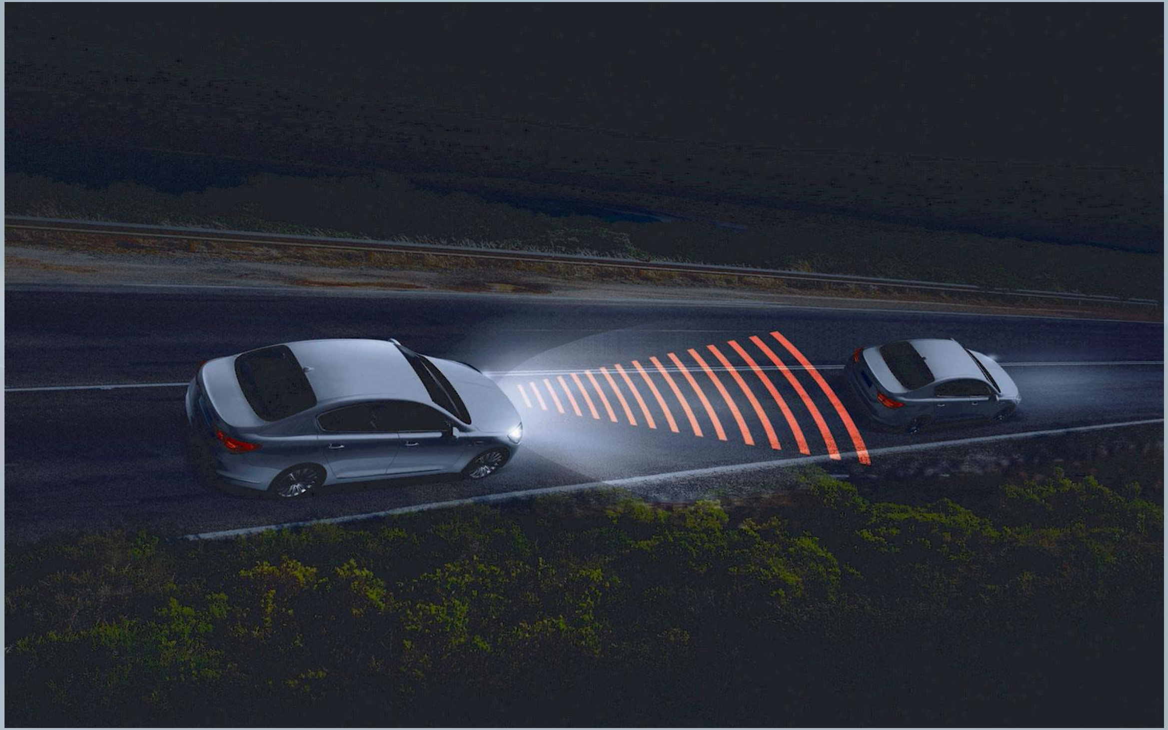
# FMCW Radar in Automotive Applications

## Technology Overview & Testing




Greg Kregoski

Automotive Business Development Manager


ROHDE&SCHWARZ

# **Rohde & Schwarz** Test Solutions for Automotive

## GNSS / eCall


## EMC

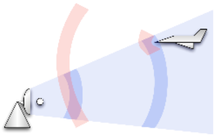

## Audio / Video / Infotainment


## Automotive Radar Solutions

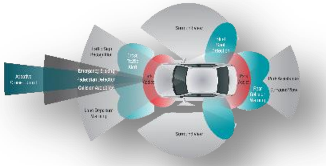

## Car2Car / Car2X


## Automotive Bus Systems

# Today’s material



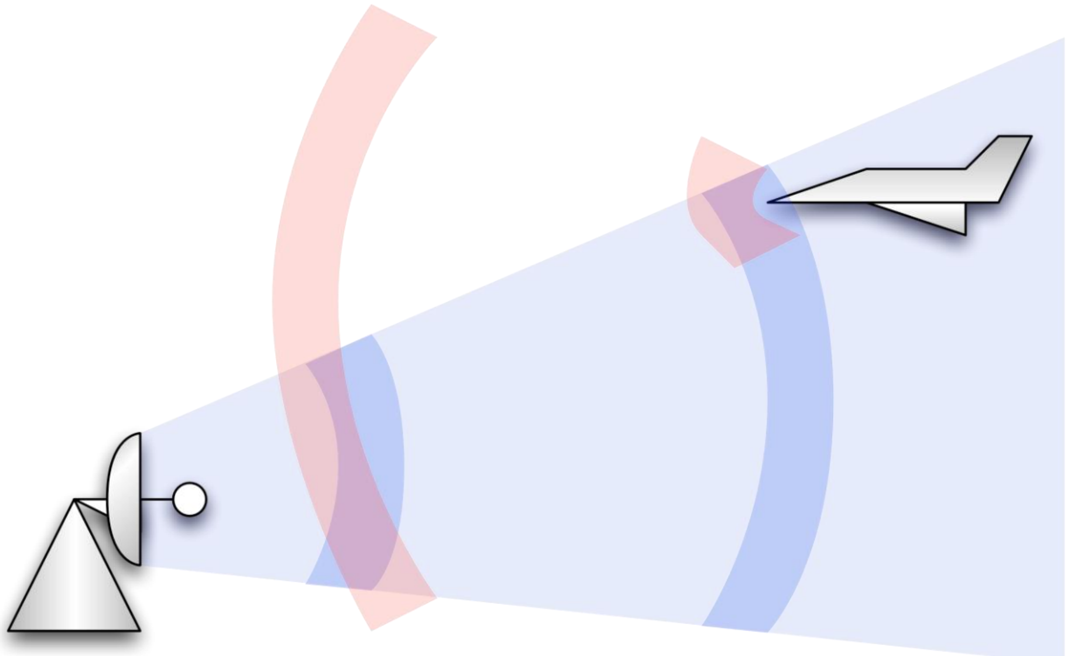
Radar Fundamental Concepts



FMCW Automotive Radar

R&S Test Solutions for Automotive Radar

# Radar fundamentals

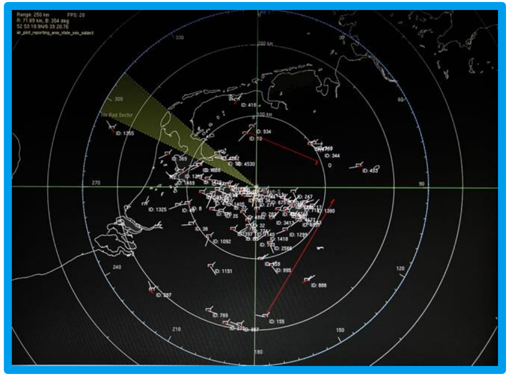


# Radar use cases

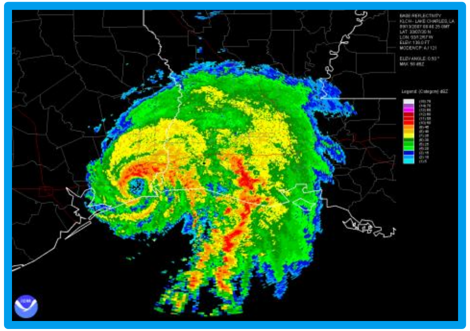
Measurement of…

- Range *
- Velocity *
- Target size (RCS)
- Azimuth angle
- Elevation angle

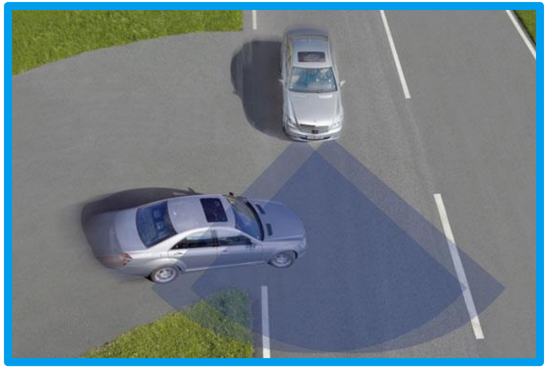
Beam Steering



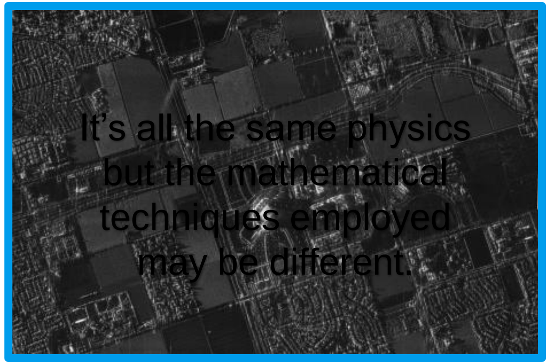
Tracking



Weather



Automotive




Imaging

Speed enforcement

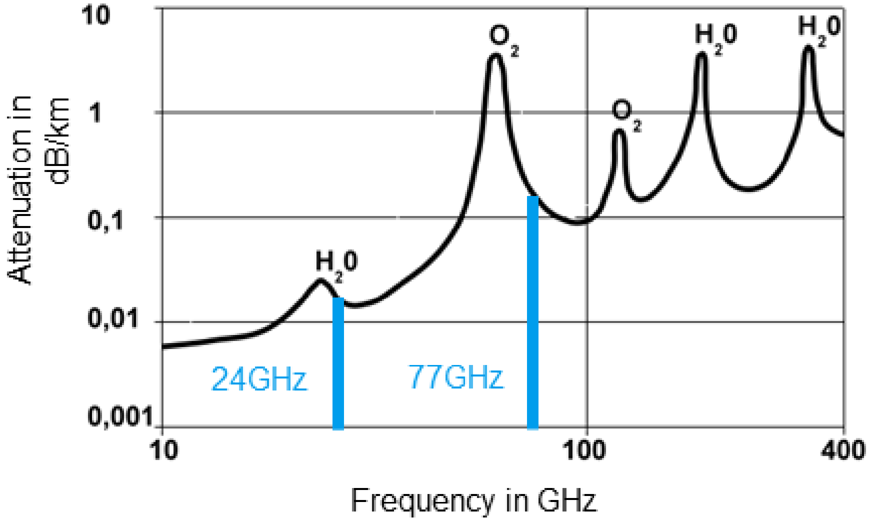
# Frequencies used in automotive radar

- Various millimeter wave frequency bands in use today
  - 24 GHz
  - 77 GHz
  - 79 GHz

- Why 24 GHz?
  - Temporary band (at least in Europe).
  - Disadvantage of having bandwidth limitations of 200 MHz bandwidth due to other usage of the ISM spectrum.

- Why 77 and 79 GHz?
  - Higher channel bandwidth available offers better range resolution.
  - Higher frequency means better velocity resolution & smaller components.

# Uniqueness of 24 & 77 GHz frequencies

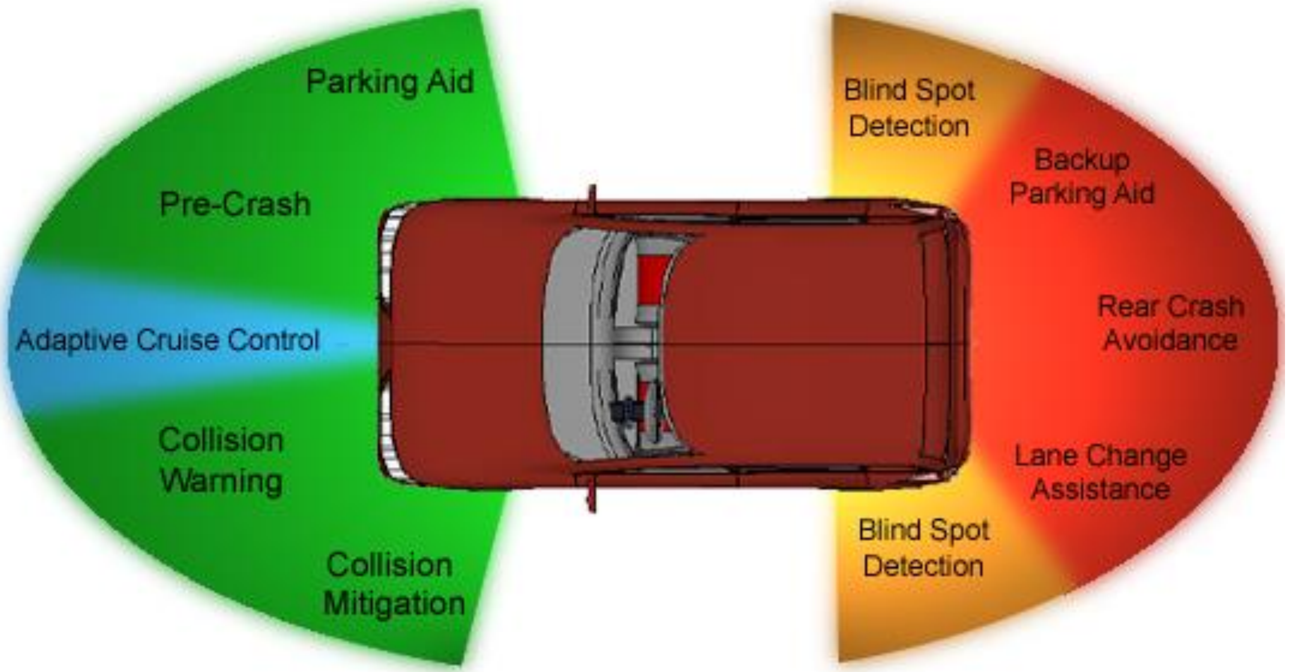



While a high attenuation might be a disadvantage for many applications, it does allow frequency reuse within very short distances.

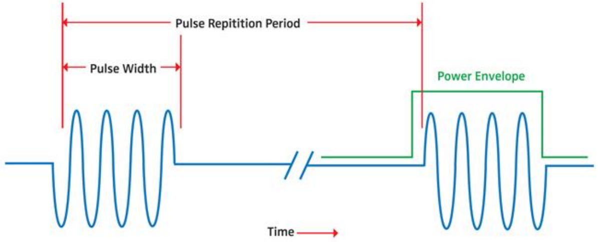
In fact, the attenuation limits the distance of mm wave radar which, in the case of having thousands of cars on the road using their radars simultaneously, is a good thing.

# Automotive specific radar applications

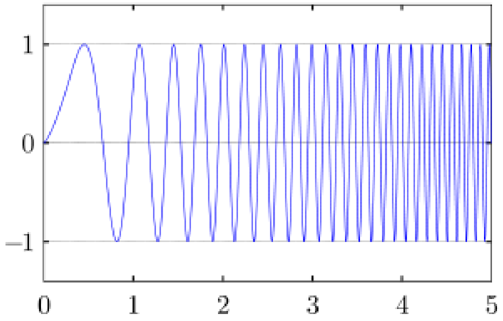
## Pulsed or FMCW?



# Pulsed vs. FMCW




**Pulsed**

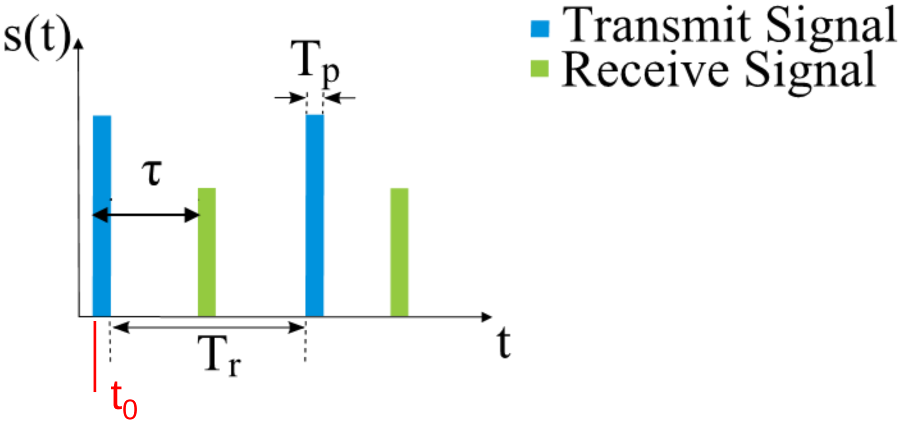



**FMCW**

(frequency modulated continuous wave)

## Which is a better fit for automotive radar?

# Range measurement - Pulsed radar



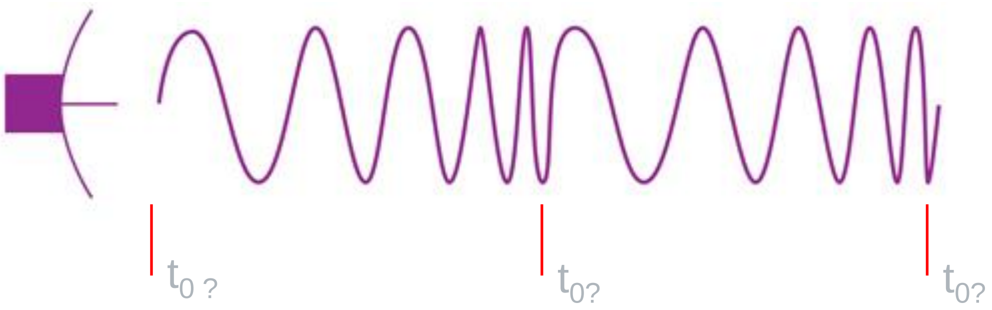

$$Range = Rate * Time$$

$$Range = c * \frac{\tau}{2}$$

c = speed of light = 299,792,458 m/s

Easy to range using pulsed radar as there is always a starting point

# Range measurement - FMCW radar

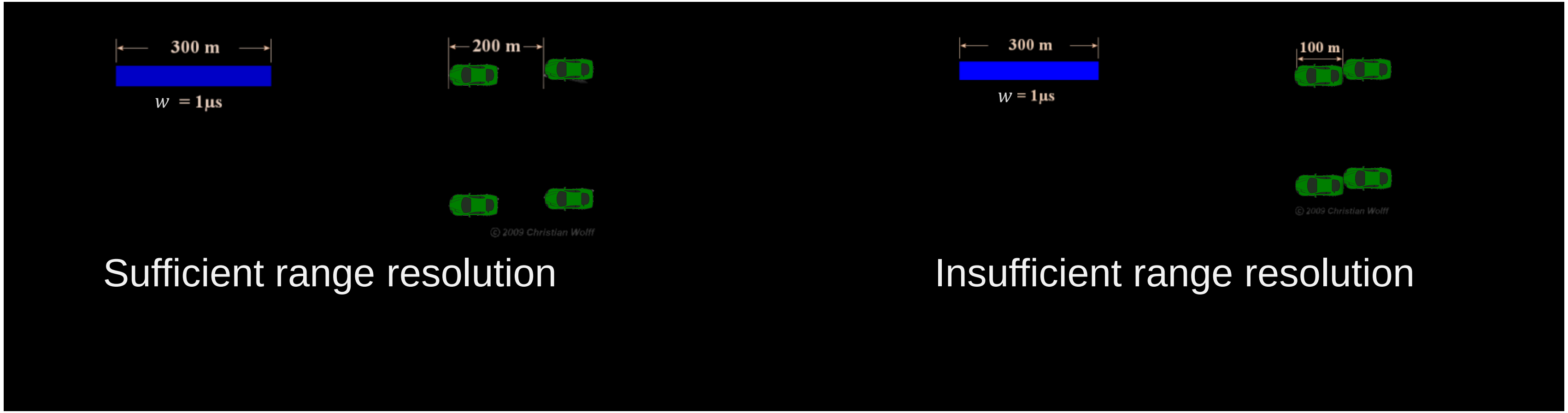



$$Range = Rate * Time$$

$$Range = c * \frac{\tau}{2}$$

How to determine range when there is no starting point? ***It's continuous!***

# Range resolution measurement – Pulsed radar

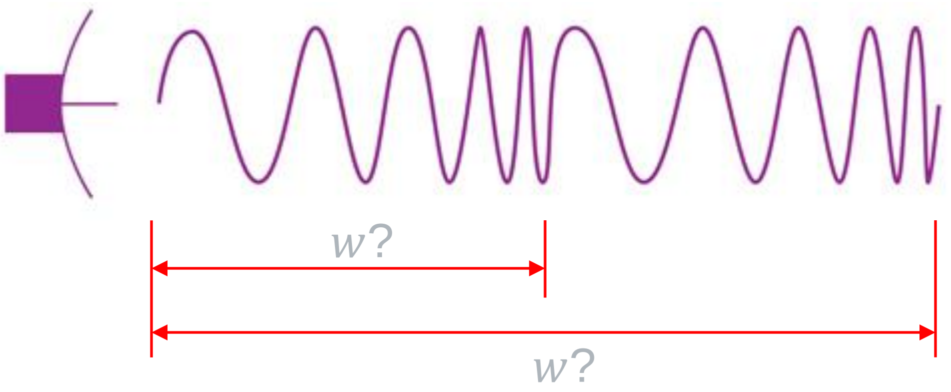



Source: radartutorial.eu

$$\Delta Range = c * \frac{w}{2}$$

Range resolution determined by adjusting pulse width

# Range resolution measurement - FMCW radar

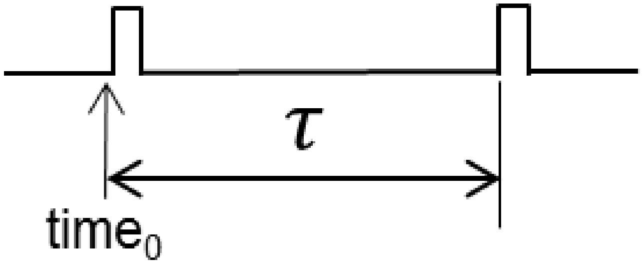



$$\Delta Range = Rate * Pulse\ Width$$

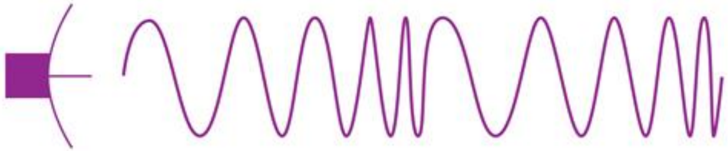
$$\Delta Range = c * \frac{w}{2}$$

How to determine Δ R when there is no pulse width? ***It's continuous!***

# How computationally intensive? – Pulsed vs. FMCW



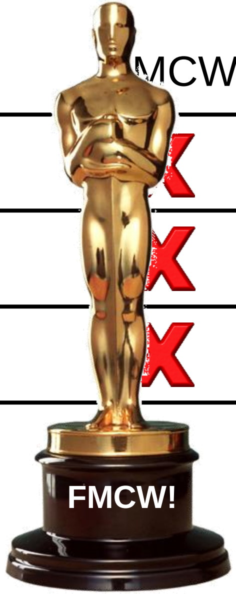

Send out a pulse and listen for a reflection



Constantly transmit and listen, while doing a lot of mathematical calculation to make sense of it all

# Best fit for automotive radar?

| | Pulsed | MCW |
|---|---|---|
| Ranging | ✓ | ✗ |
| Range Resolution | ✓ | ✗ |
| Required computational power | ✓ | ✗ |




# Computational power is relatively inexpensive



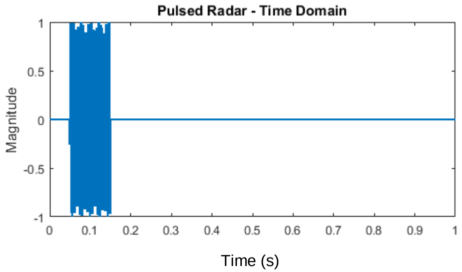

Faster processors make the real-time complex math required for FMCW possible. Lower cost of these processors makes the distribution of many of them around the perimeter of the automobile more realizable.

# The downside of pulsed radar

Time Domain

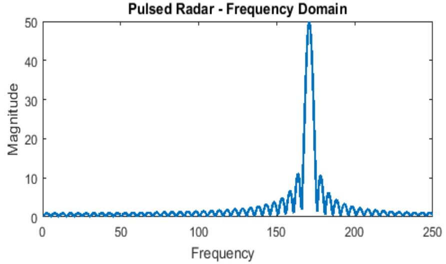
Spectrum Domain

Pulsed Radar

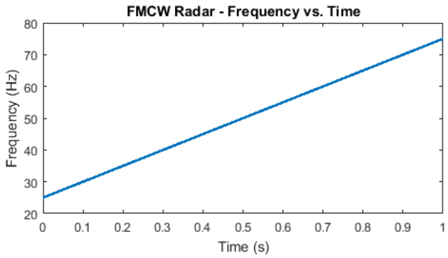


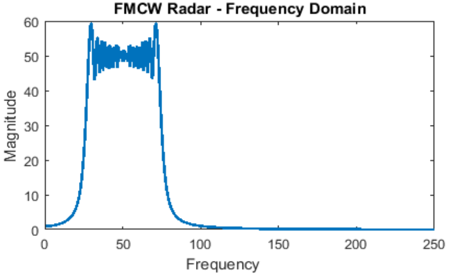

**Pulsed radar downsides**

- Wide bandwidth
- Higher power requirements
- Can't listen while transmit
- Expensive

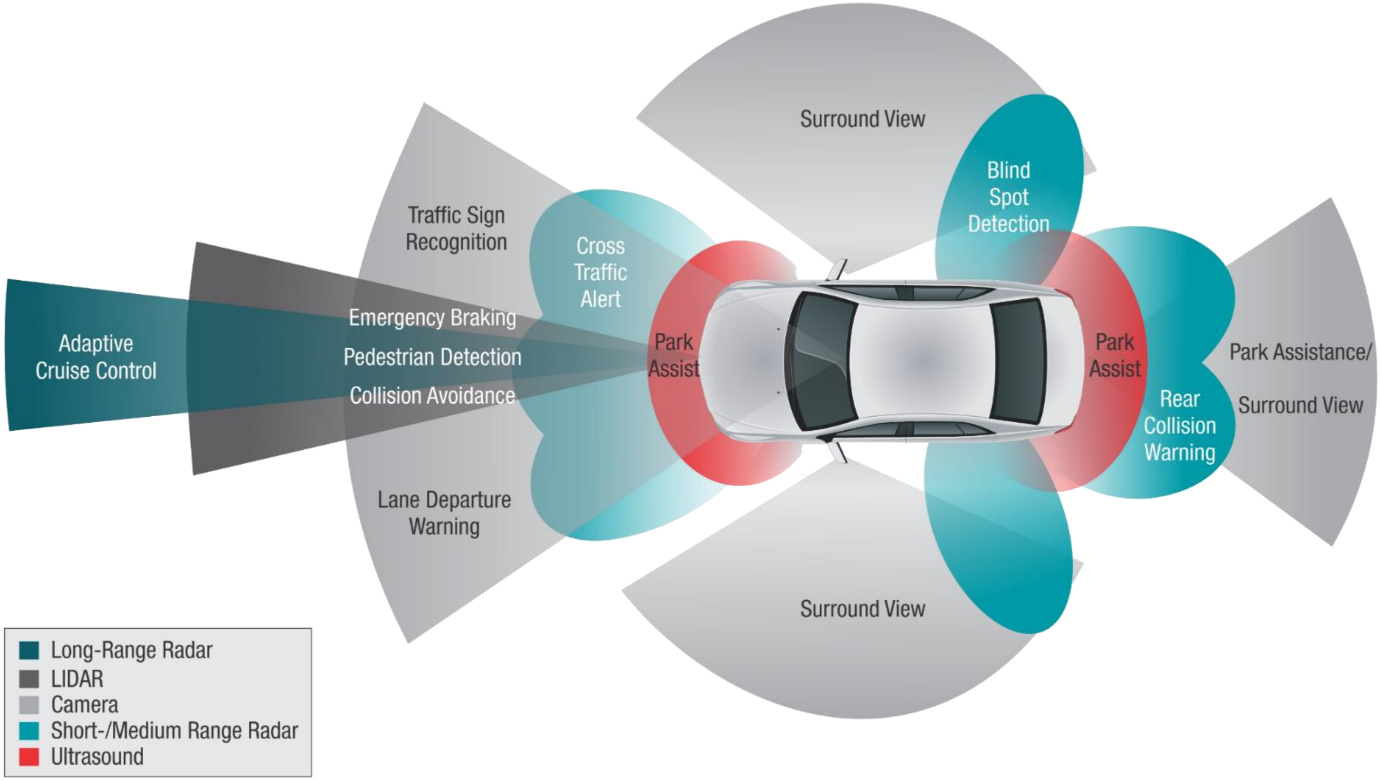



FMCW Radar



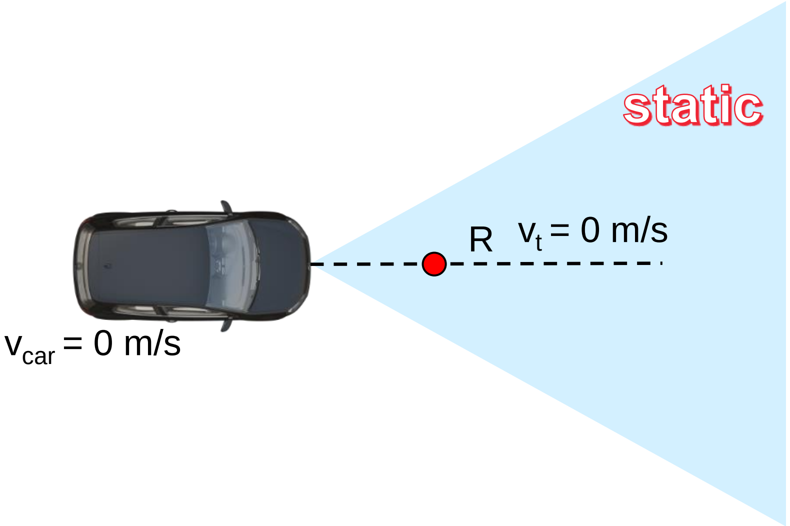



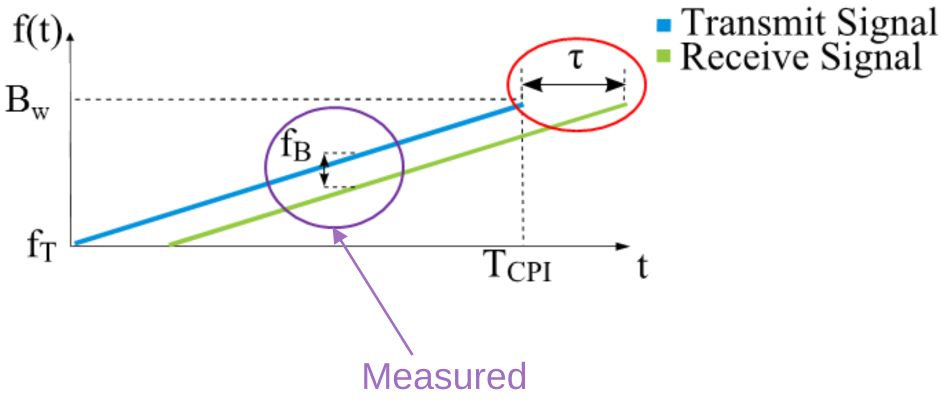
# FMCW automotive radar



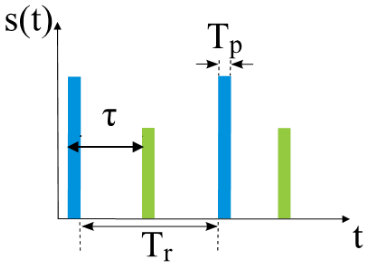
# Range measurement - FMCW radar

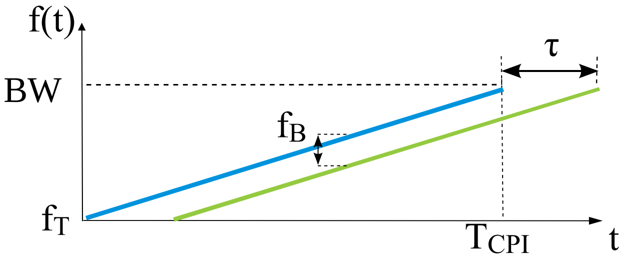
- **Static** target at a certain range R



# Range measurement - FMCW radar




$$Range = \frac{c}{2} * \tau$$

$$\frac{f_B}{B_w} = \frac{\tau}{T_{CPI}}$$

Plug $\tau$ into pulsed range equation

Solving for $\tau$

$$\tau = \frac{f_B}{B_w} * TCP_I$$

$$R = \frac{c}{2} \cdot \frac{f_B}{B_w} T_{CPI}$$

**Range determined by beat frequency**

$$f_B = \frac{2}{c} \cdot \frac{B_w}{T_{CPI}} R$$

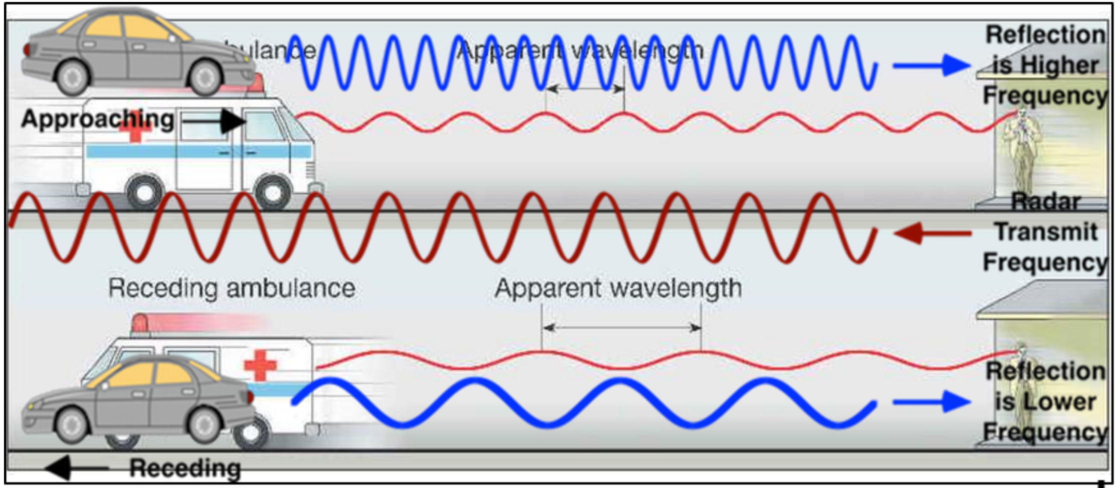
Because this beat frequency refers to the range contribution it's often referred to as $f_R$

# Let’s add some velocity to the picture

The Doppler effect, or Doppler shift, is named after the Austrian physicist Christian Doppler
(1803-53)

# Doppler shift is a measure of radial velocity

- What is Doppler?
  - A perceived wavelength shift taking place between a source and listener.

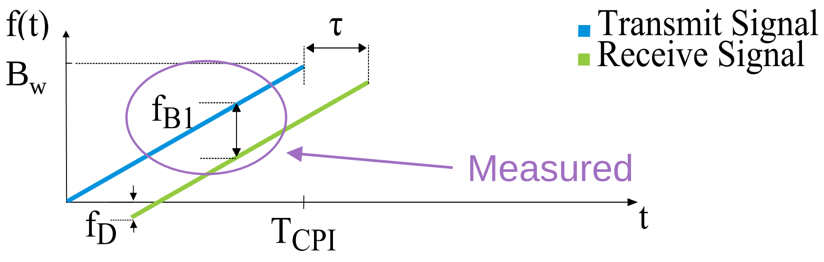


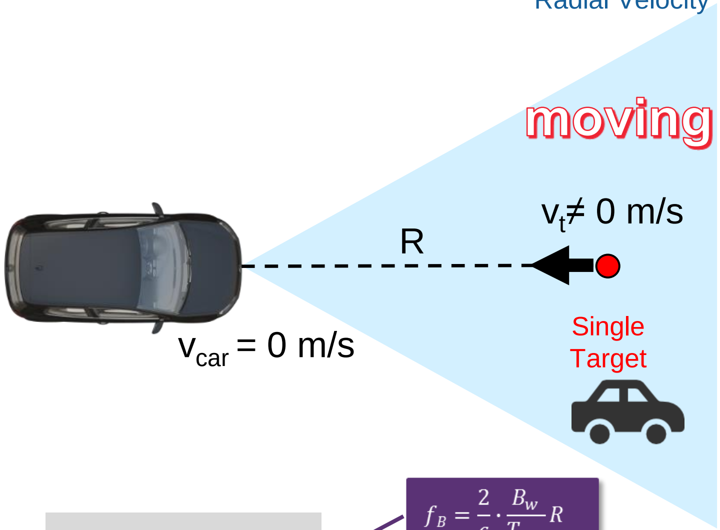

sound radar

# Range and velocity* measurement



- A single **moving** target at a certain range R

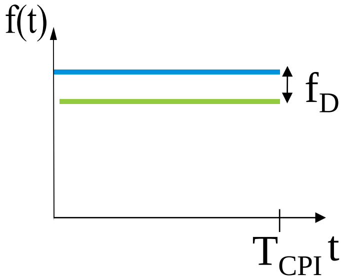



$$f_B = \frac{2}{c} \cdot \frac{B_w}{T_{CPI}} R$$

$$f_{B1} = f_R + \boldsymbol{f_D}$$

$$f_{B1} = \boxed{\frac{2}{c}\frac{B_W}{T_{CPI}} R} - \frac{2}{\lambda} * vt$$

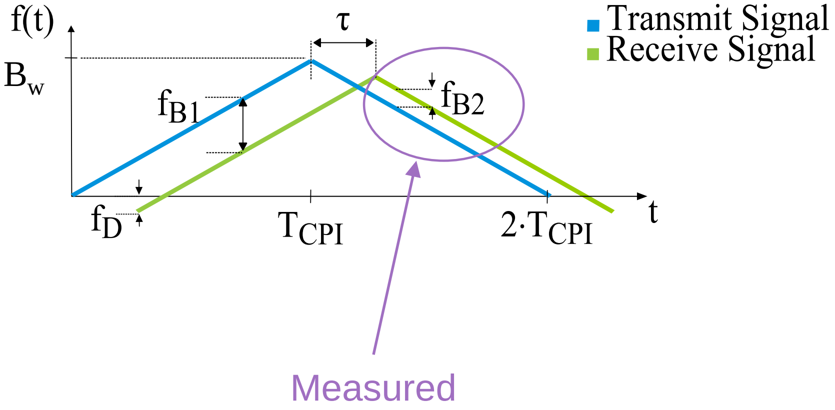


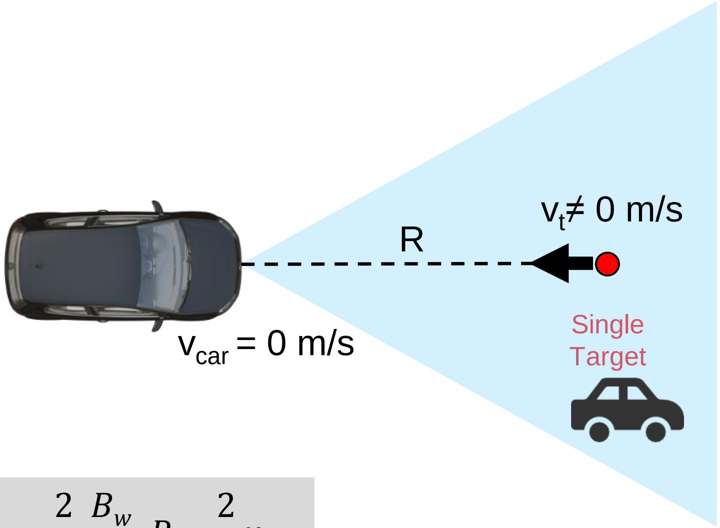

$f_D$ is the Doppler shift. Note it is not due to range!

We now have **one** equation with **two** unknowns including R and $v_t$. Therefore it cannot be solved in its present state. *What's needed is a second measurement.*

# Range **and** velocity measurement

- Second transmitted slope




$$f_{B1} = \frac{2}{c}\frac{B_w}{T_{CPI}}R - \frac{2}{\lambda}v_t$$

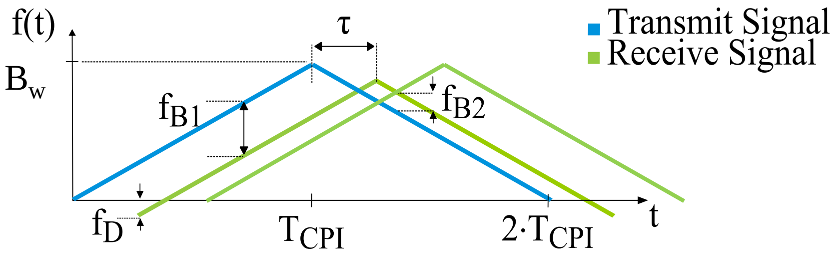
$$f_{B2} = -\frac{2}{c}\frac{B_w}{T_{CPI}}R - \frac{2}{\lambda}v_t$$

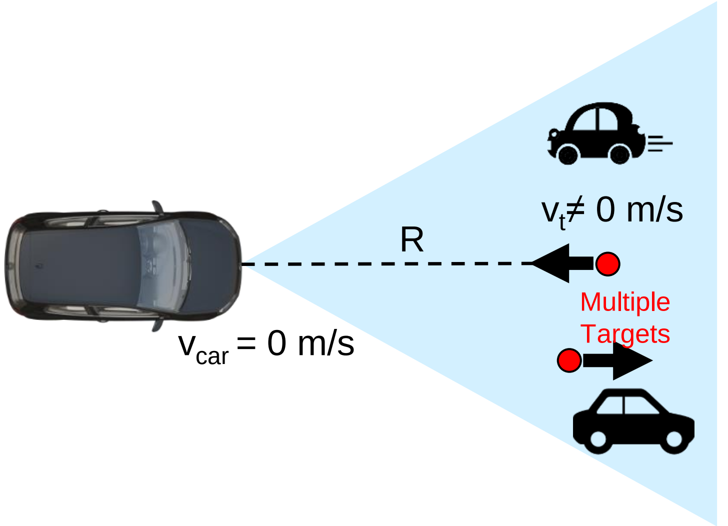
Now we have two equations and two unknowns, R and $v_t$.

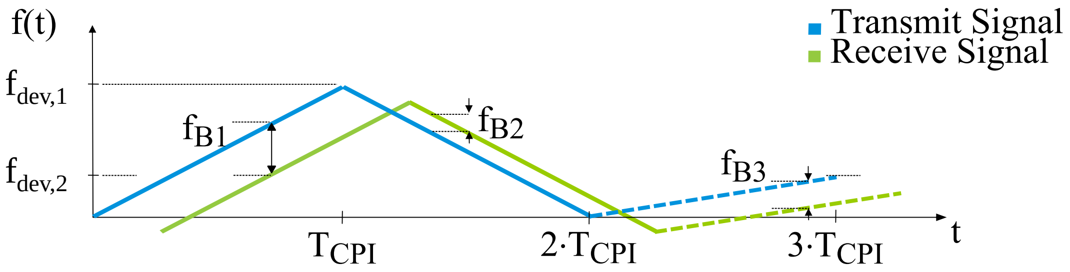
**Therefore we can now solve for both R and $v_t$.**

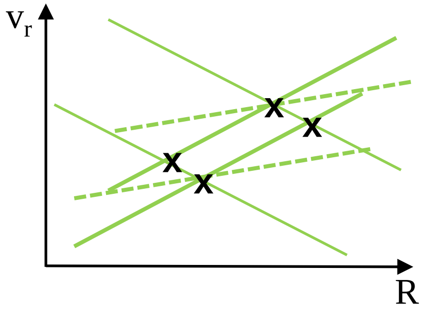
# Range and velocity measurement

- What about 2 targets?

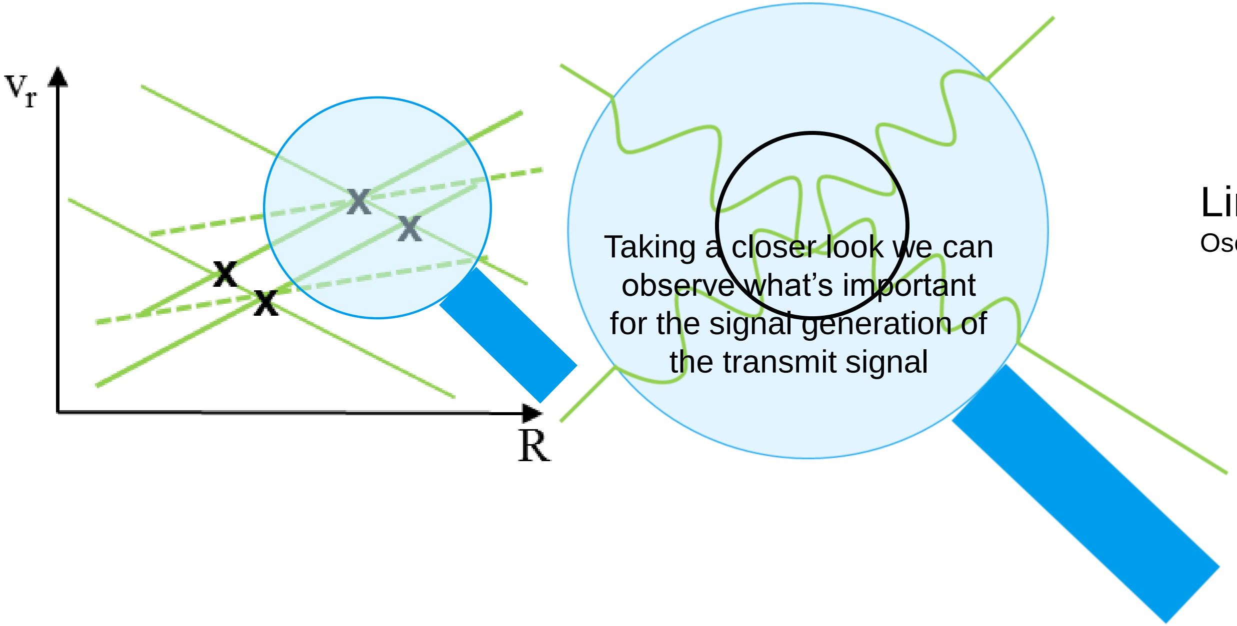


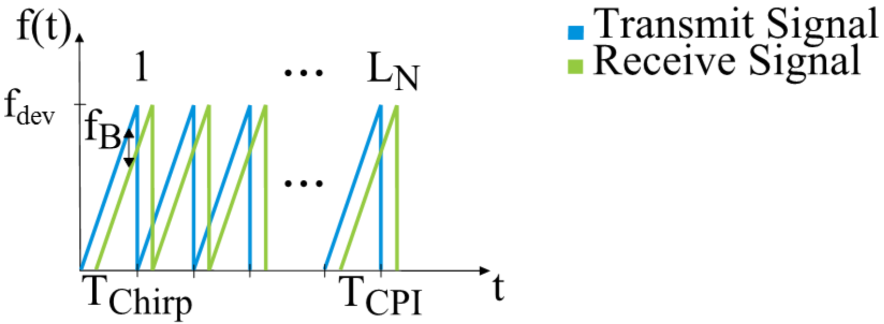
# Measurement issues with FMCW

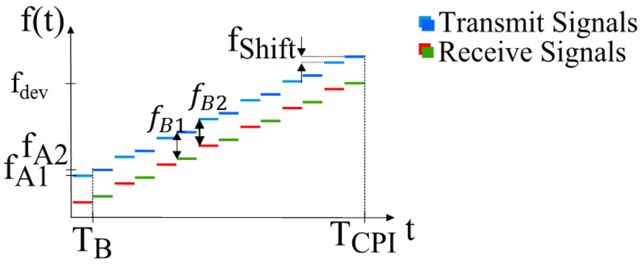



## Linearity of chirp

Oscillations change crossover points

# Other waveforms ever needed?



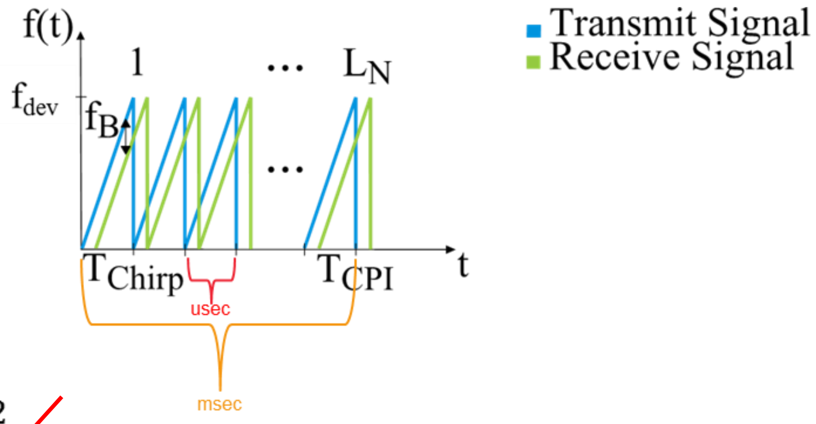




**Chirp Sequence**

**MFSK**

# Chirp sequence waveform

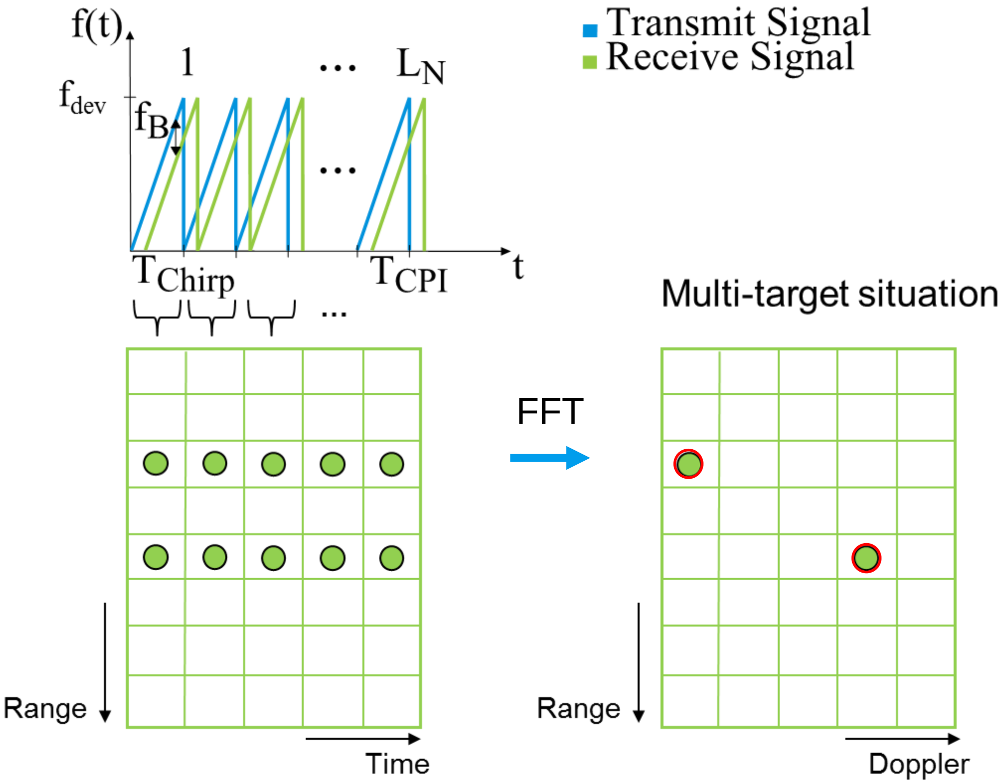
- Each chirp has it's own beat frequency.
- Very short chirps so $f_D$ can be ignored.
- Chirp length much shorter than entire CPI.
- Doppler determined by *measure phase difference* between these short chirps.
- Works for multiple targets *over one CPI*.



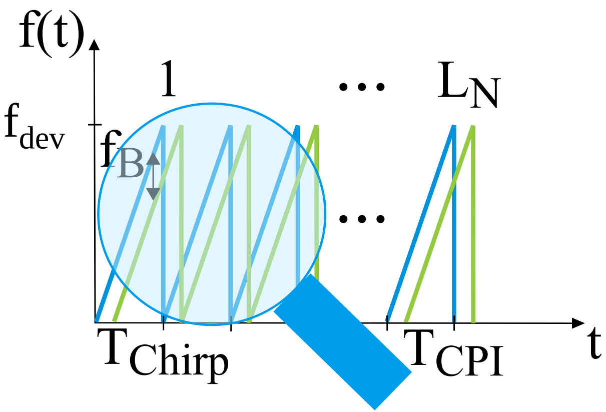

$$f_B = \frac{2B_W}{cT_{Chirp}} R - \cancel{\frac{2}{\lambda} v_r}$$

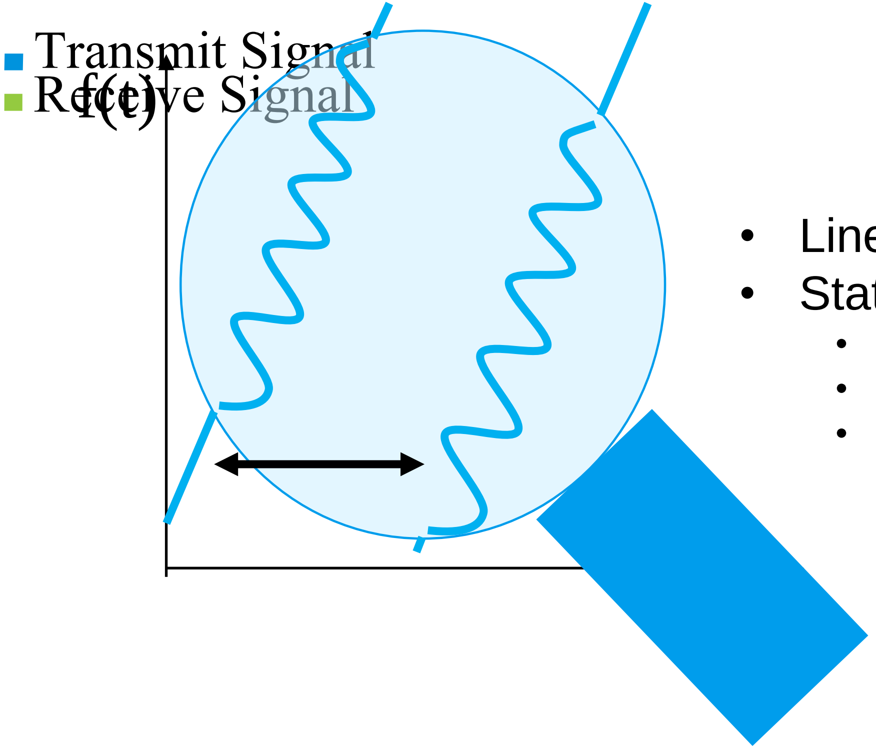
$$f_B = \frac{2Bw}{cT_{chirp}} R = f_R$$

# Chirp sequence



# Measurement issues with a chirp sequence




- Linearity
- Statistics
  - Timing
  - Phase
  - Repeatability

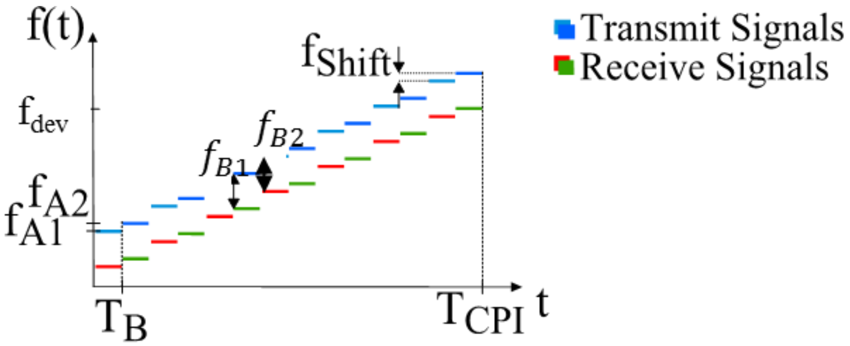
# Multi-frequency shift keying (MFSK) waveform

- It's FMCW with a small twist
  - Same CPI, same Bw and same slope.
  - But using two frequency shifted (MFSK) transmit signals
- This technique allows us to measure $f_B$ and $\Delta\phi$ between $f_B$

$$f_B = f_{B1} = f_{B2}$$

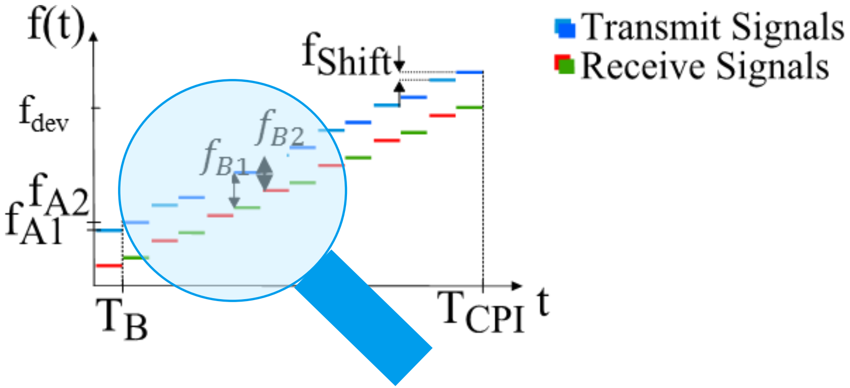
$$\boxed{f_B = -\frac{2}{\lambda} v_r - \frac{2f_{dev}}{cT_{CPI}} R}$$

$$\boxed{\Delta\varphi = \frac{4\pi T_B}{\lambda} v_r - \frac{4f_{Shift}}{c} R}$$




2 equations ($f_B$ and $\Delta\varphi$) and 2 unknowns.
We can solve for velocity and range.

# Measurement issues with MFSK

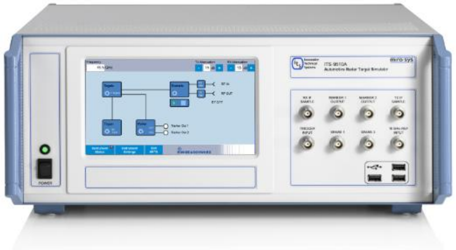



Parameters to be measured

- Shift frequency
- Timing
- Linearity

# R&S Automotive Radar Test Solutions

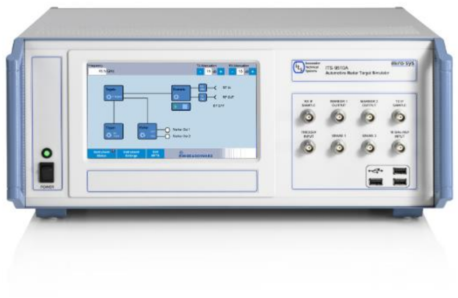
# Test & measurement tools for the lab

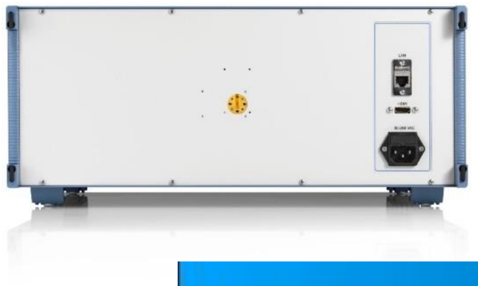


**ARTS** - Automotive Radar Target Simulator
- Real-time simulation of up to four targets

**FSW** – Signal & Spectrum Analyzer
- **FSW-K60/K60C/K60H** Transient Measurements
- **160/320/500/2000** MHz Analysis Bandwidth*

# ARTS – Automotive Radar Target Simulator

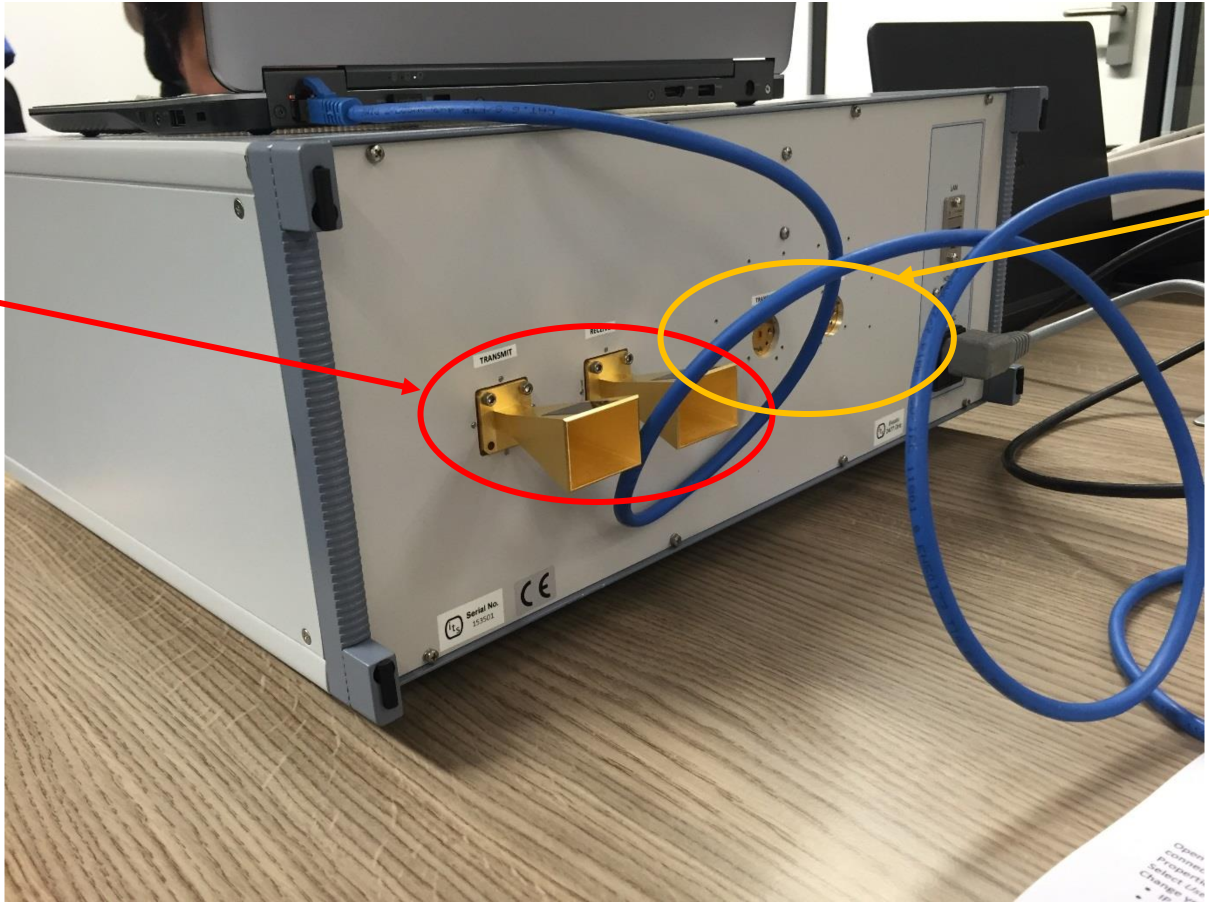




- Operating at 24 and 77/79 GHz radar bands
- *Simulates range, Doppler and RCS*
- Up to 1000 MHz bandwidth
- Delay Range: 9m – 2400m<br>step size: 6cm
- Speed Range: 0km/h – 700km/h<br>step size: < 4mm/s

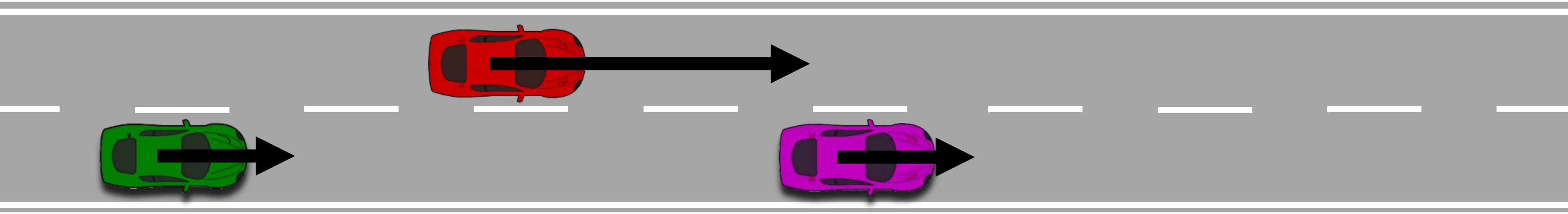
**It modifies the original radar transmission**

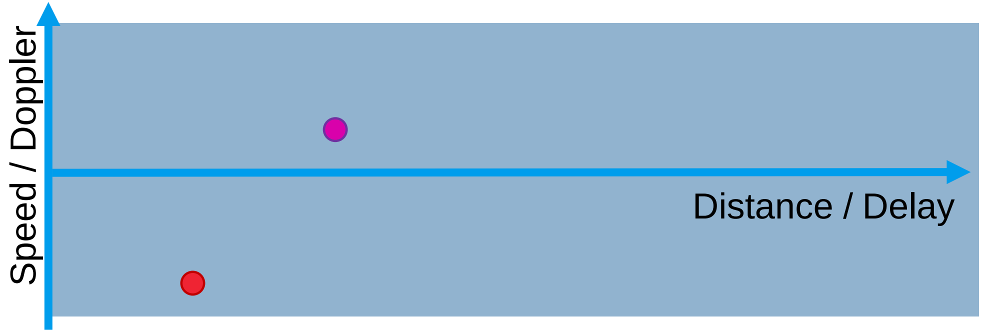
24 GHz
Bistatic



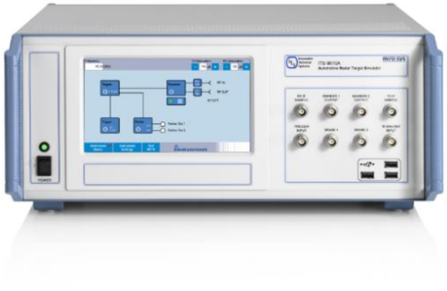

77 GHz
Bistatic

# The real world needs to be simulated realistically





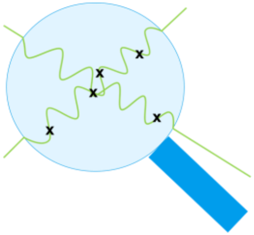

target 1
target 2
Possible location



# Advantages of ARTS

- Reduces size of needed chamber.
- Simulates targets in non-static environments.
- Simulates various target sizes (user adjustable).
- Simulates up to 4 targets.
- Fast with updates every millisecond.
- Programmable.

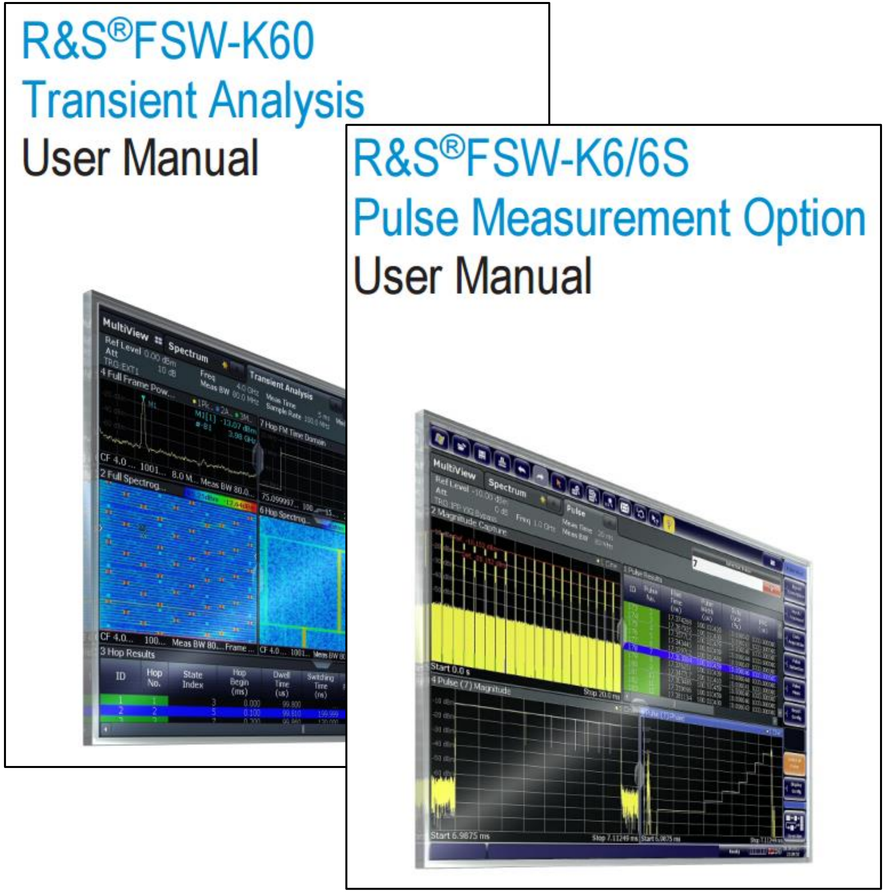
# FSW – Signal & Spectrum Analyzer



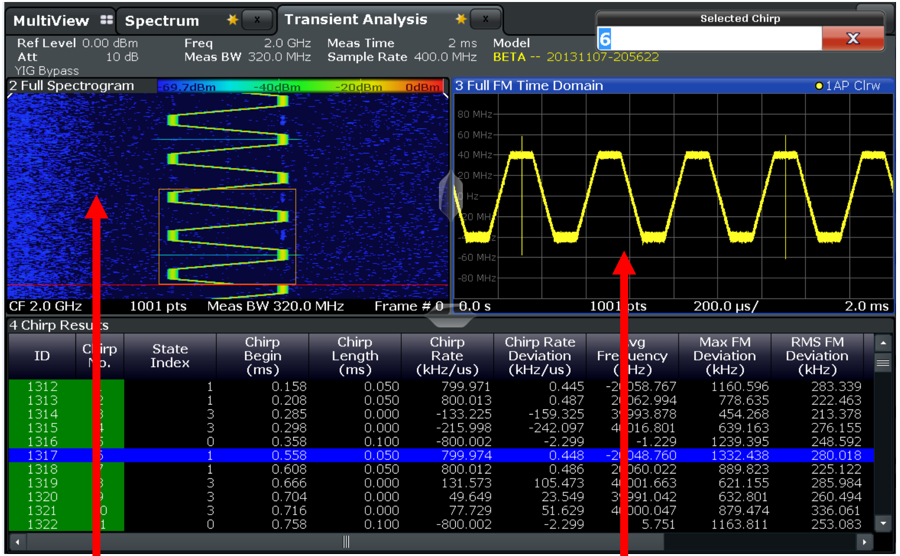
- Various models up to 85 GHz
- BW up to 500 MHz internally
- BW extension up to 2 GHz through the use of external R&S RTO digital scope
- Transient & chirp analysis
- Wide dynamic range

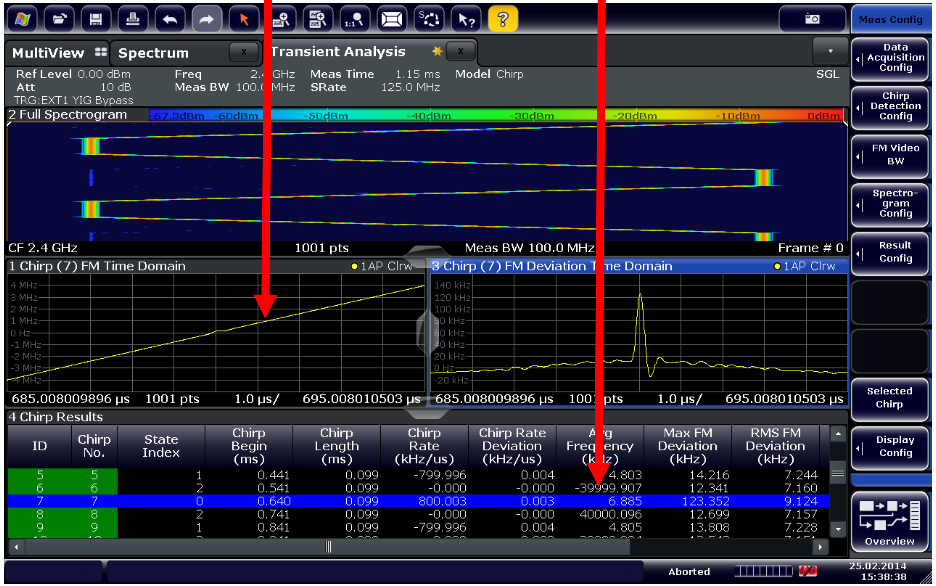
# Specific FSW Measurements

- Spectrum
- Spectrogram (waterfall)
- Frequency vs. time
- Amplitude vs. time
- Phase vs. time
- Full captured signal
    - Or selected region
    - Or detected chirp
- Chirp and linearity analysis
- Pulsed or FMCW chirps
- Chirp rate, deviation from linearity ramp
- Chirp states
- Chirp tabular results
- Long term statistics



# FSW Transient Analysis Screen Shots




Check the frequency deviation of the chirp at each time instant.

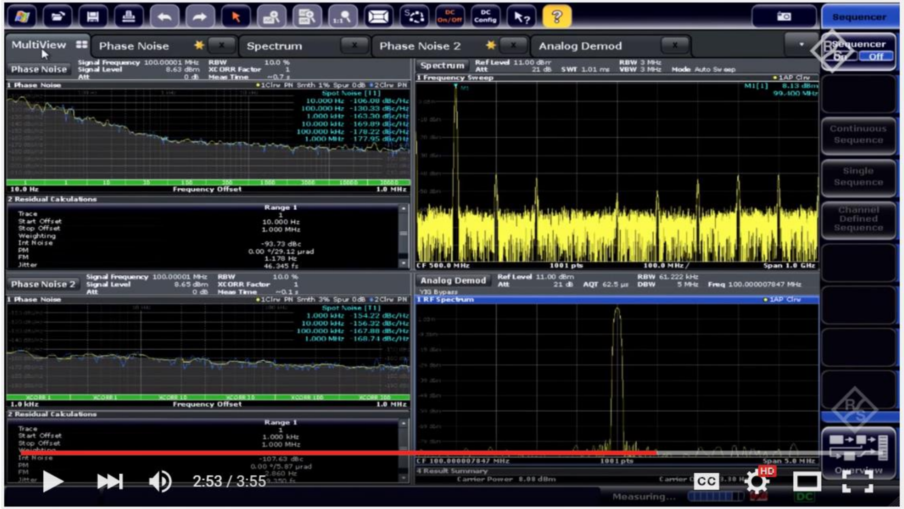
Summary table with critical chirp specifications.

Analyze the Full spectrogram of the signal in waterfall view.

Analyze the chirp in an intuitive time-frequency plot.

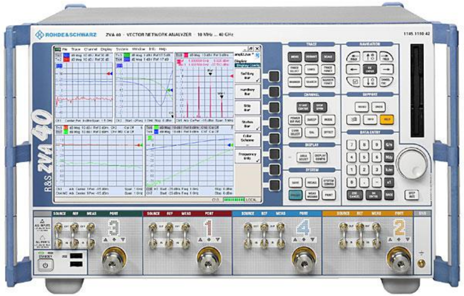
# FSWP – Phase Noise Analyzer

- Various models up to 50 GHz
- Measure spectral purity of signal sources such as synthesizers and VCOs
- Extremely low phase noise
- Very fast measurements
- Can be upgraded to a signal and spectrum analyzer



# Other fun toys to test radar…

- Frequency multipliers
- Harmonic mixers
- Vector network analyzers
- Wideband vector signal generator

# Questions?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