Defence and Automotive Radar – Differences and Commonalities

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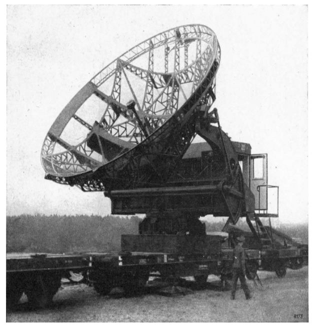
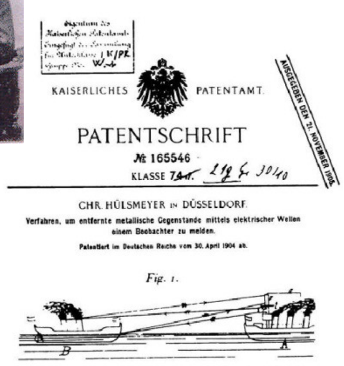
What can radar do for **me**?

1904
Christian Hülsmeyer
Telemobiloskop



1945
Radar applied in civil aviation, naval navigation, meteorology, medicine



1930s
Research in radar,
Pulse Radars using low carrier frequencies

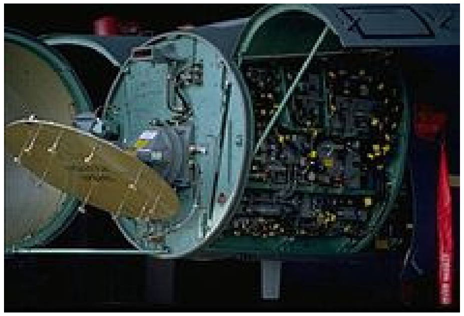
Late 1990s
Automotive Applications, high carrier frequencies, variety of waveforms, reduced system complexity, cheap unit prices

Radar in A/D

- **Large variety of radar systems**
  - Surveillance and acquisition
  - Navigation, Aviation
  - Early warning
  - Fire control and tracking
  - Missile guidance and seekers
  - Many other applications

- **Radars with specific**
  - Carrier frequencies
  - Bandwidth
  - Waveform
  - Resolutions
  - Accuracy
  - Antennas

Multiple Radars
D Band 1-2GHz Air Search
E/F Band 2-4GHz Air/Surface Search
I Band 8-10GHz Navigation
I/J Band 8-20GHz Sea Dart Fire Control



APG-70 Pulse Doppler Radar, I/J Band used in F-15 Eagle Fighter.
e.g. Target Recognition, SAR, LPI Capability

PAVE Phased Array Warning System (PAWE) radar in Alaska
Intercontinental ballistic missile warning, space surveillance and sattelite tracking

Pulse Radar

- Measurement of

  Target range R due to signal

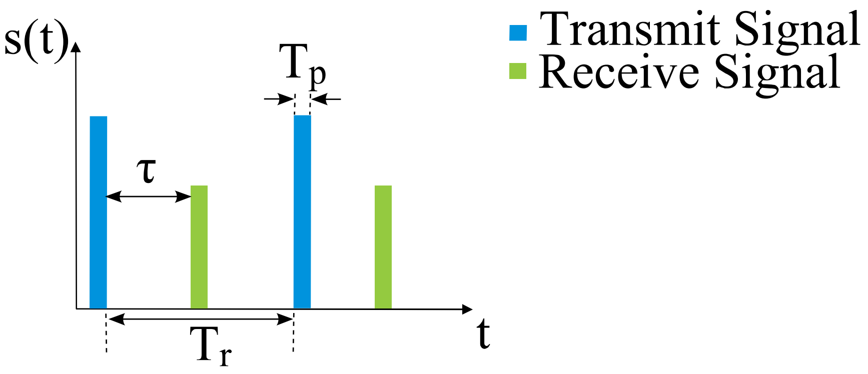
  propagation time $\tau = \frac{2R}{c}$

  Radial velocity v_r due to

  Doppler shift $f_D = -f_T \frac{2v_r}{c} = -\frac{2v_r}{\lambda}$

  Azimuth and **Elevation Angle** using

  mechanical steering / digital beamforming



Unambiguous Range: $R_{max} = \frac{c}{2} \cdot T_r$

Range Resolution: $\Delta R = \frac{c}{2} \cdot T_p$

Pulse Radar using Pulse Compression

- Measurement of

  Target range R due to signal

  propagation time $\tau = \frac{2R}{c}$

  Radial velocity v_r due to

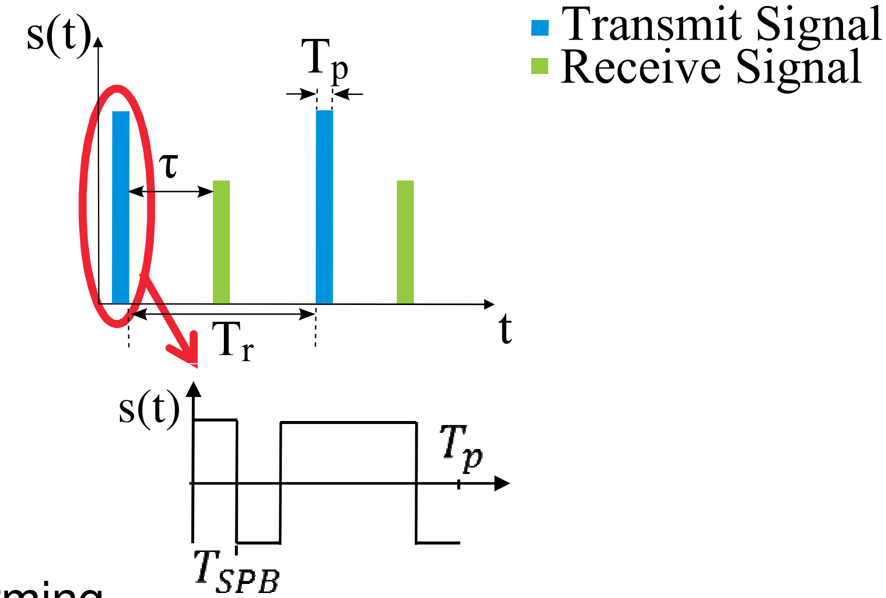
  Doppler shift $f_D = -f_T \frac{2v_r}{c} = -\frac{2v_r}{\lambda}$

  Azimuth and **Elevation Angle** using mechanical steering / digital beamforming

Unambiguous Range: $R_{max} = \frac{c}{2} \cdot T_r$

Range Resolution:

Performance	Impulse	Pulse compression
Range Resolution	$\Delta R = \frac{c}{2} \cdot T_p$	$\Delta R = \frac{c}{2} \cdot T_{SPB}$
Unambiguous Range	$R_{max} = \frac{c}{2} \cdot T_r$	



Performance	Impulse	Pulse compression
Range Resolution	$\Delta R = \frac{c}{2} \cdot T_p$	$\Delta R = \frac{c}{2} \cdot T_{SPB}$
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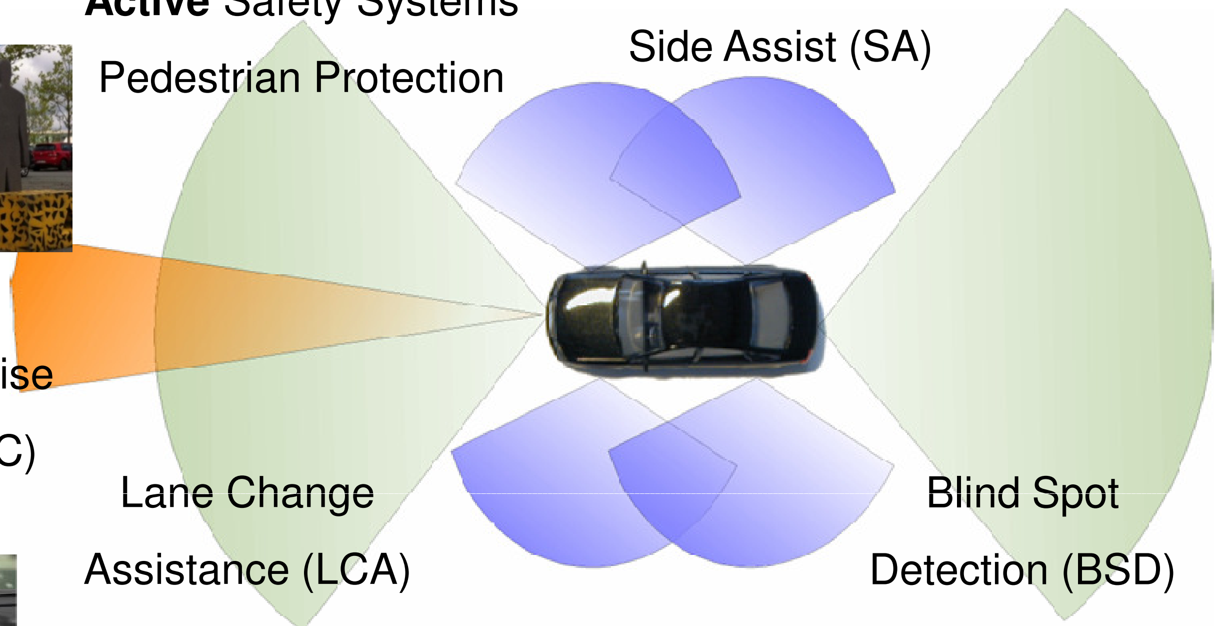
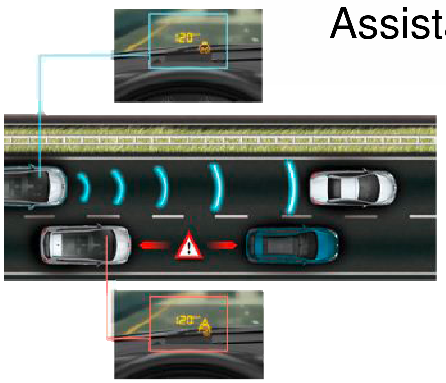
Radar in Automotive Applications



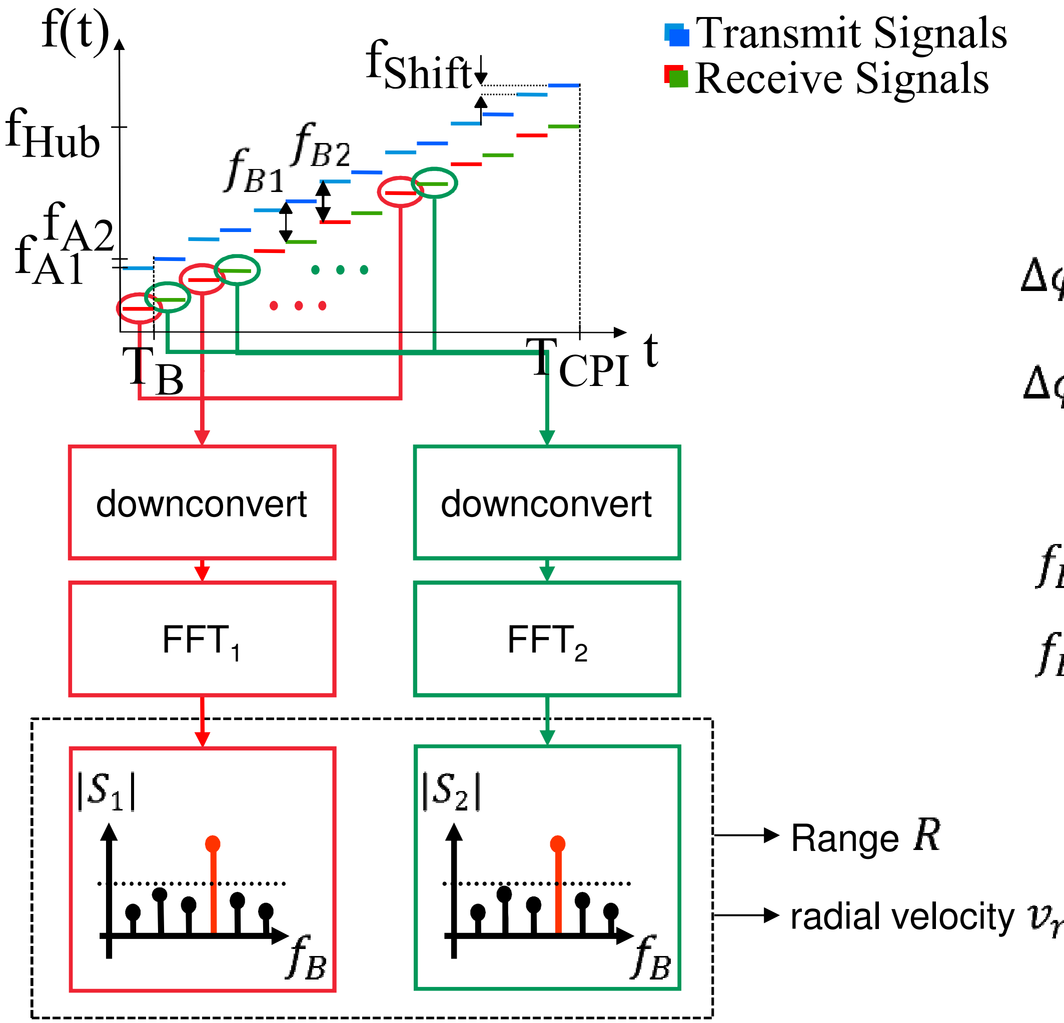


Automotive Radar

- **Pulse Waveform for Automotive Radar?**
  - blind range
  - Complex system architecture
  - No real simultaneous range and radial velocity measurement

- **Desire of**
  - low power and low system complexity
  - no mechanically moving parts
  - high measurement accuracy
  - simultaneous range, radial velocity, azimuth angle measurement
  - high range, radial velocity and azimuth resolution
  - low price

MFSK-CW Waveform



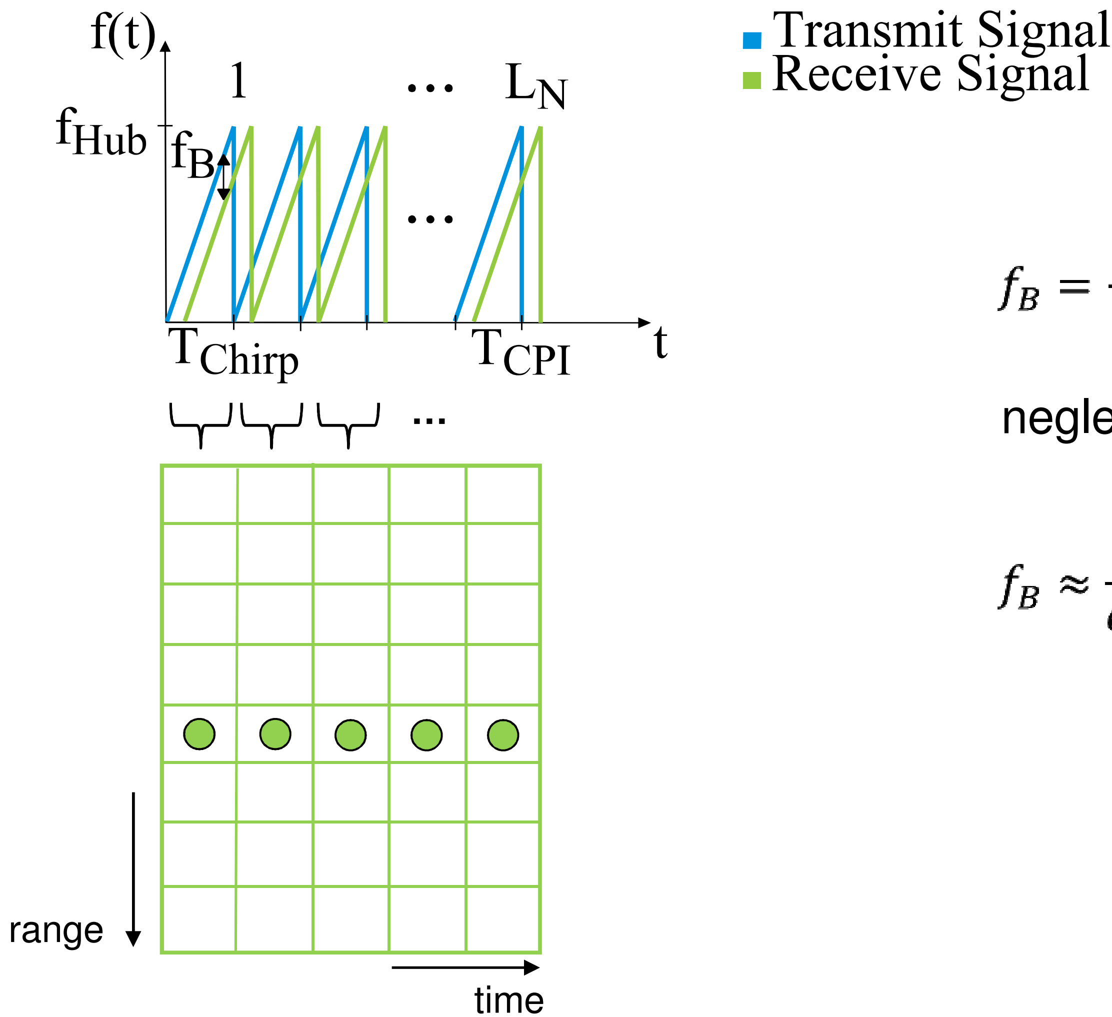
$$\Delta\varphi = \arg(S_1) - \arg(S_2)$$

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

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

$$f_B = -\frac{2}{\lambda} v_r - \frac{2 f_{Hub}}{c T_{CPI}} R$$

Chirp Sequence Waveform

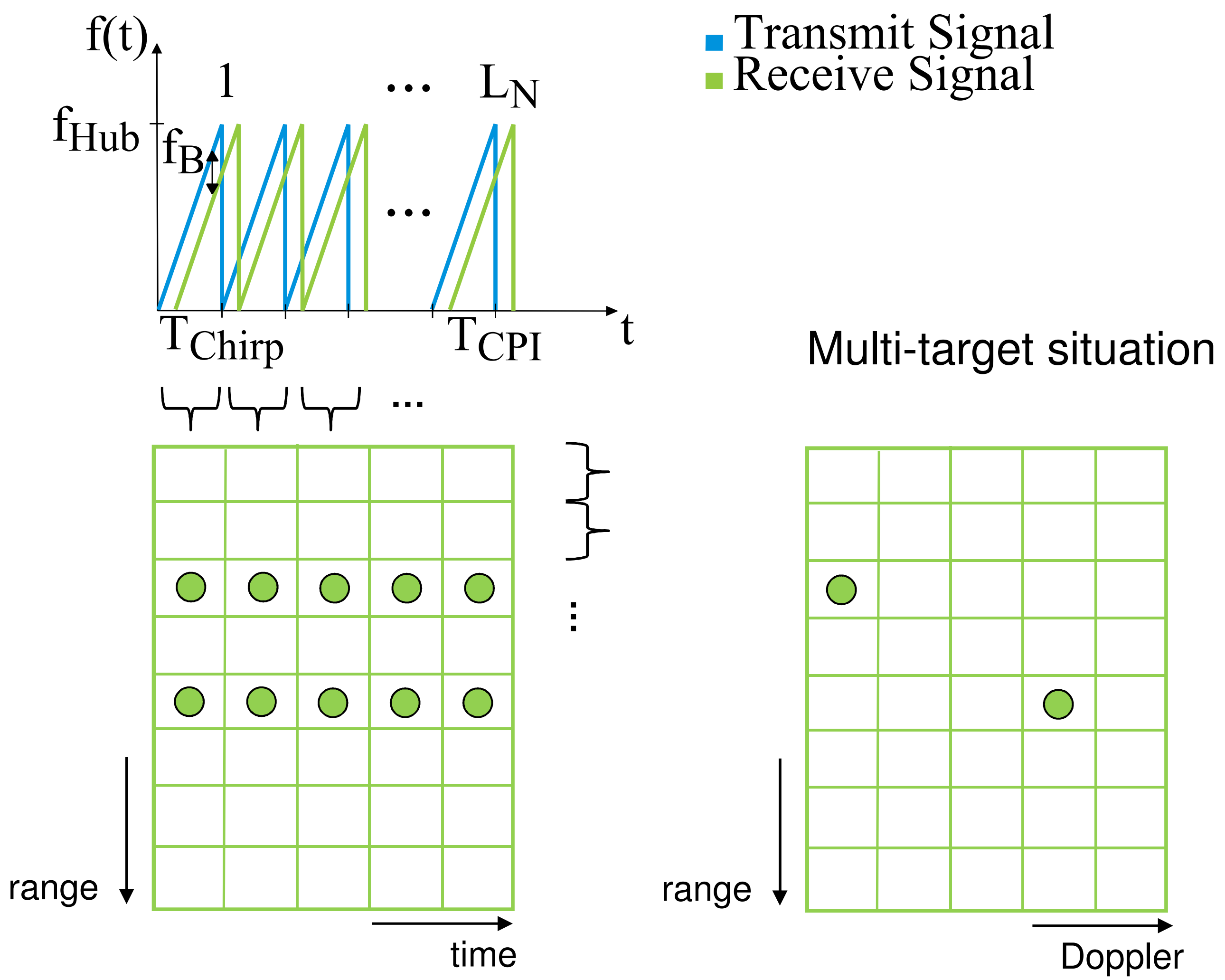


$$f_B = -\frac{2}{\lambda} v_r + \frac{2 f_{Hub}}{c T_{Chirp}} R$$

neglect able Doppler shift

$$f_B \approx \frac{2 f_{Hub}}{c T_{Chirp}} R$$

Chirp Sequence Waveform: Multi-Target Resolution



Radar in A/D vs. Automotive Radar

A/D	Automotive
Surveillance and **acquisition**, early **warning**, Fire control, tracking, classification, Missile guidance …	**Surveillance** and **acquisition**, early **warning**, tracking, classification
• Robust against interference, ECM, ECCM • Low detectability for others • Detection of stealth targets	• Multi-Target measurement and resolution • Short measurement time • High robustness IP67, IP68, IP69K (No mechanically moving parts) • **low price**
Variety of Specifications • R_{max} near … very far (x000km) • ΔR some meters … hundred of meters • $\hat{R}$ as accurate as it can be • v_{max} slow … very fast (x000m/s) • Δv some meters ... hundret of meters • $\hat{v}$ as accurate as possible	**Similar specifications for any kind of automotive radar sensor** • $R_{max} < 50 \ldots 300m$ • $\Delta R = 0.5 \ldots 1m$ • $\hat{R} < 0.5\%$ • $v_{max} = \pm 70m/s$ • $\Delta v = 0.1m/s$ • $\hat{v} < 0.5\%$
Less Regulations • Frequency Bands HF … mm-Wave • Radiated Power up to MW	**Regulations** • Frequency Bands 24GHz / 77GHz • Radiated Power mW • Bandwidth 50MHz … 1GHz

What can radar do for **me**?

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Christian Hülsmeyer
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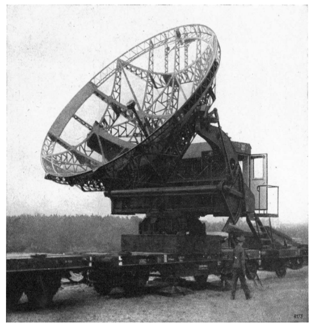

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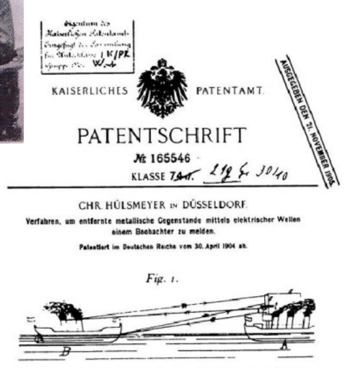
KAISERLICHES PATENTAMT
PATENTSCHRIFT
№ 165546
KLASSE 74d.
CHR. HÜLSMEYER IN DÜSSELDORF.
Verfahren, um entfernte metallische Gegenstände mittels elektrischer Wellen einem Beobachter zu melden.
Patentiert im Deutschen Reiche vom 30. April 1904 ab.
Fig. 1.

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What can I do for radar?

A/D Radar

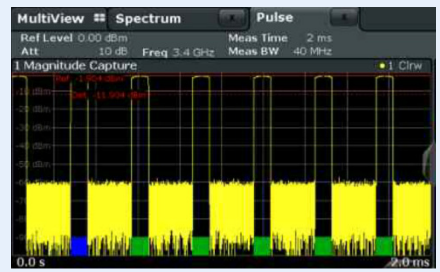
Variety of carrier frequencies, bandwidths, waveforms, designs
Increased demand for mm wave technology
Demand for very **low phase noise** and great spurious free dynamic range
Antennas using Monopulse, DBF, AESA with high power antenna array elements

Automotive Radar

Mainly at 24GHz / 77GHz, narrow bandwidths, **different waveforms**, low transmit power, **low unit price**

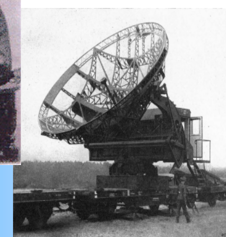
Test and Measurement Solutions

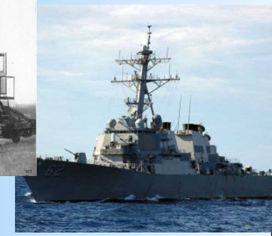
Signal Generation and Evaluation



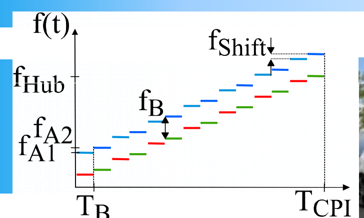
- Pulse Form, Bandwidth, Spectrum, Linearity, Complex Waveforms, Timing, Statistics,...
- Group delay, phase noise
- **Antenna** measurements (e.g. TRM calibration)
- Simulation of Targets
- **Automotive** Conformity to Standards e.g. Bandwidth, radiated Power, Accuracy

Conclusion





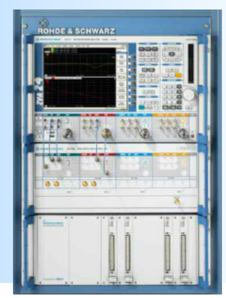
A/D Radar



Automotive Radar

2 Pulse Results

ID	Pulse No.	Pulse Width (us)	Freq Err RMS (kHz)	Chirp Rate (MHz/us)
1	1	80.677	20.039	0.250
2	2	80.677	19.985	0.250
3	3	80.677	19.998	0.250
4	4	80.677	20.072	0.250
5	5	80.677	20.147	0.250
6	6	80.677	19.980	0.250



Test and Measurement Solutions