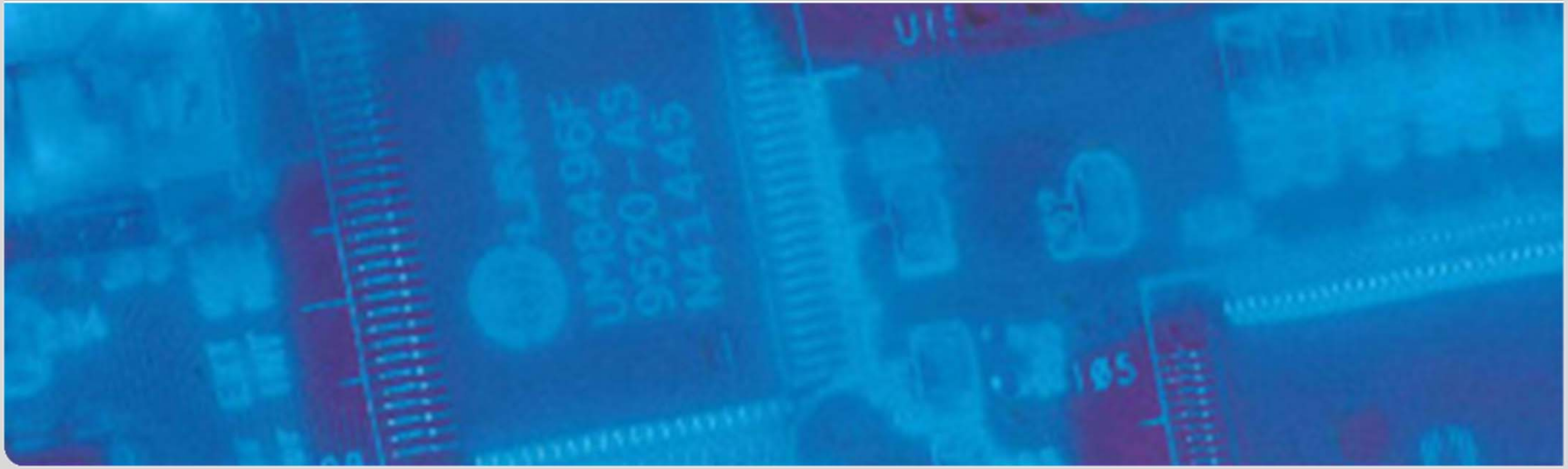
Karlsruher Institut für Technologie

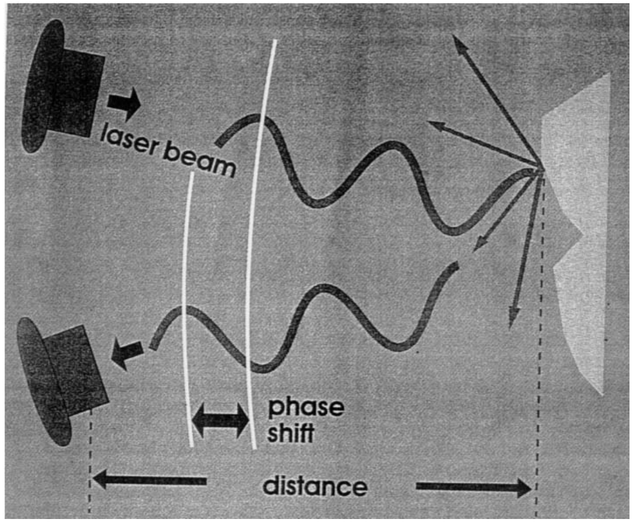
Integrierte Intelligente Sensoren Sommersemester 2012 27.06.2012

Wilhelm Stork

Institut für Technik der Informationsverarbeitung (ITIV)



Laserradar



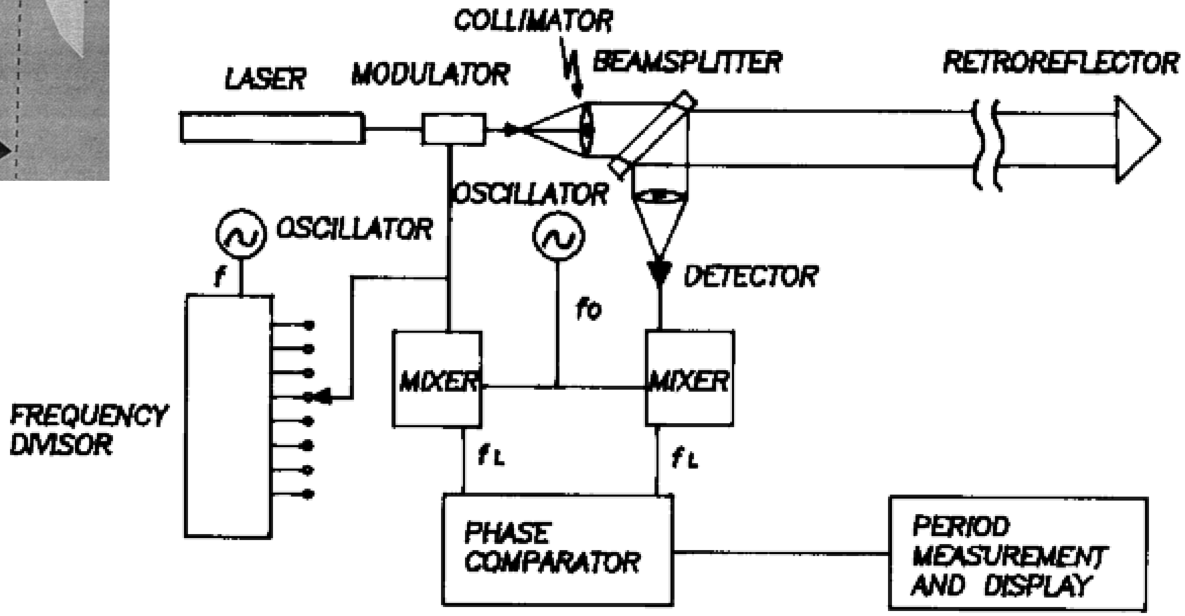


FIGURE 4 A wave modulation distance meter.

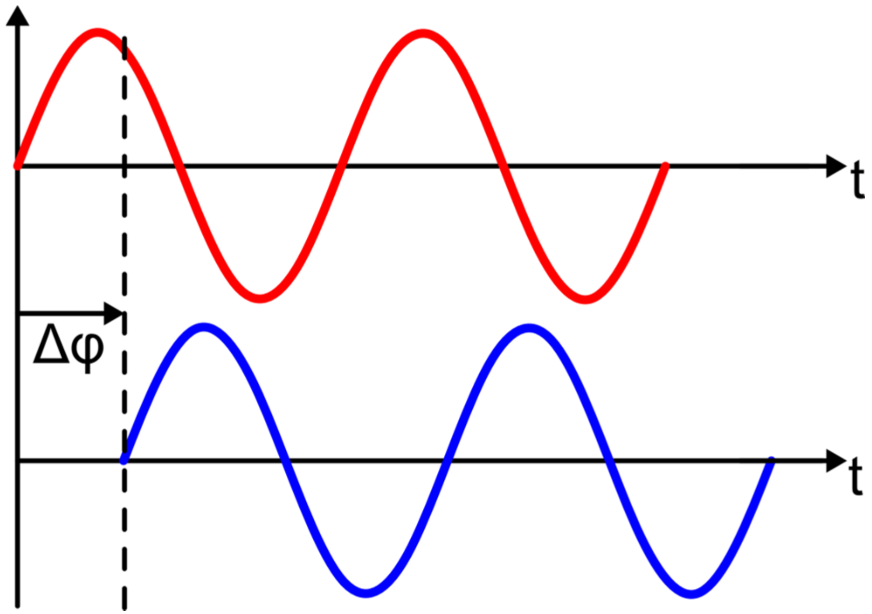
Systemüberblick – Phasenmessprinzip

- Phasenverschiebung

$$\Delta\varphi = 2\pi\left(f \cdot \frac{2D}{c} + n\right)$$

- Eindeutigkeitsbereich

$$D_{\max} = \frac{c}{2f}$$

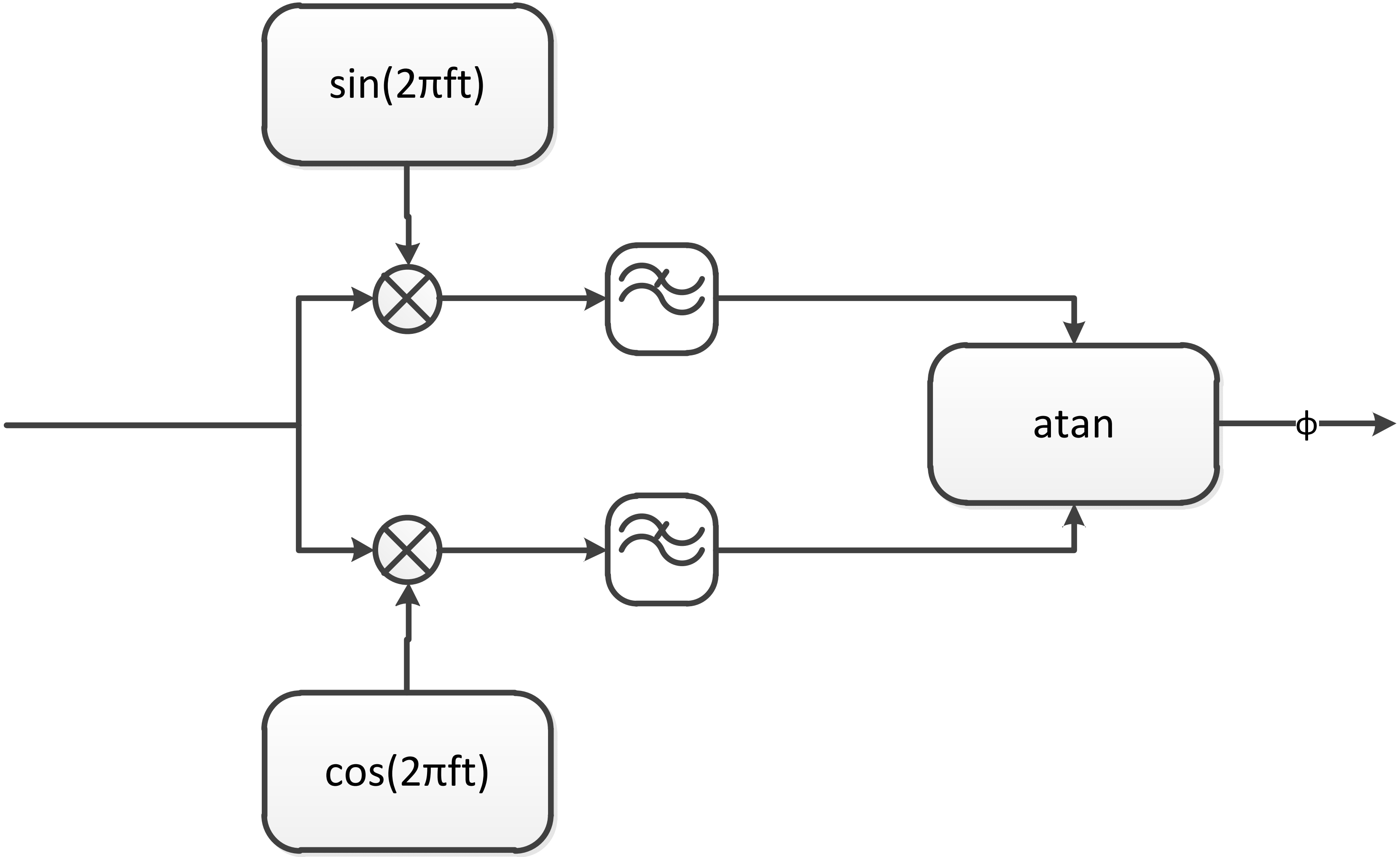


$$f_1 = 5\mathrm{MHz} \;\rightarrow\; D_{\max} = 30\mathrm{m}; \qquad f_2 = 100\mathrm{MHz} \;\rightarrow\; D_{\max} = 1.5\mathrm{m}$$

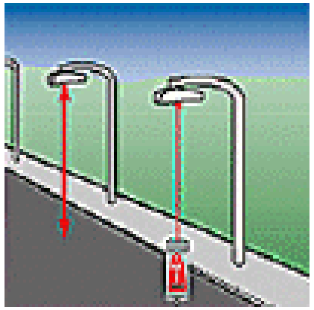
- Phasenauflösung

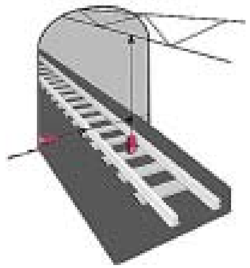
$$\mathrm{d}\varphi = 2\pi \cdot \frac{\mathrm{d}D}{D_{\max}} = 2\pi \cdot \frac{2\mathrm{cm}}{30\mathrm{m}} = 2\pi \cdot \frac{1\mathrm{mm}}{1.5\mathrm{m}} \cong 4\mathrm{mrad}$$

Messprinzip – IQ-Demodulator



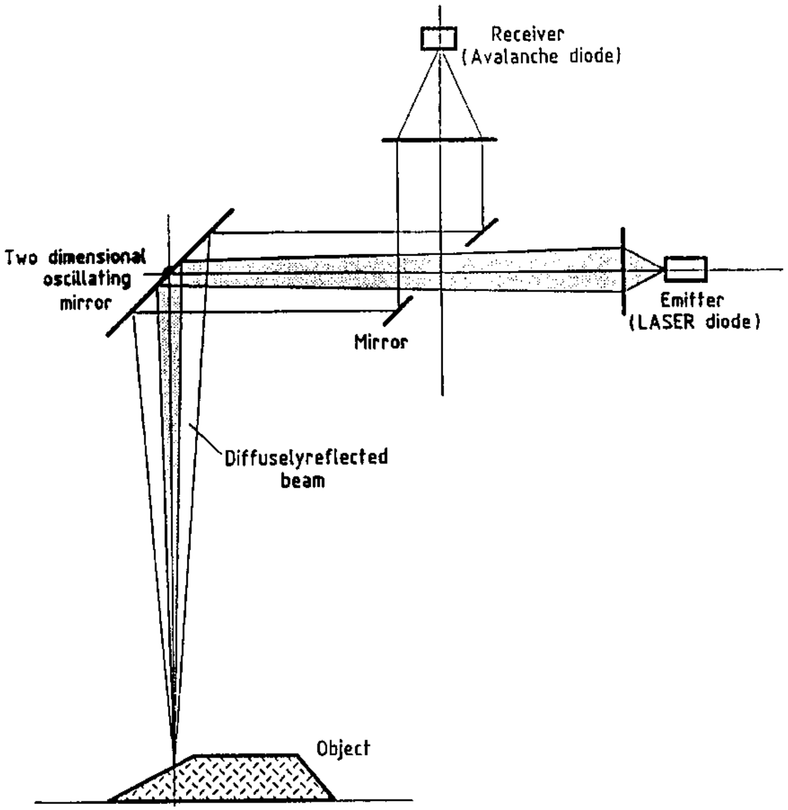
Laserradar

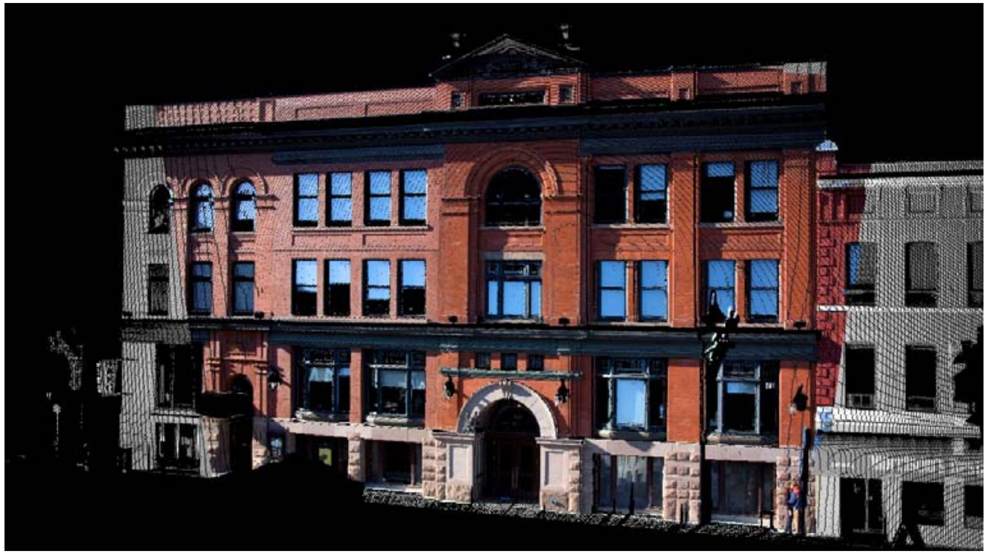




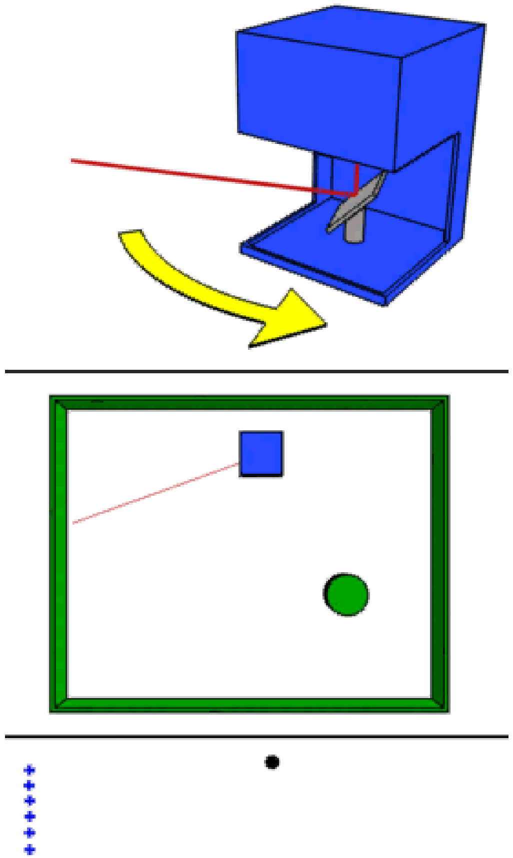
Automatische Deformationsmessungen in einem Tunnel

Laserradar mit Feld für 3D Messung

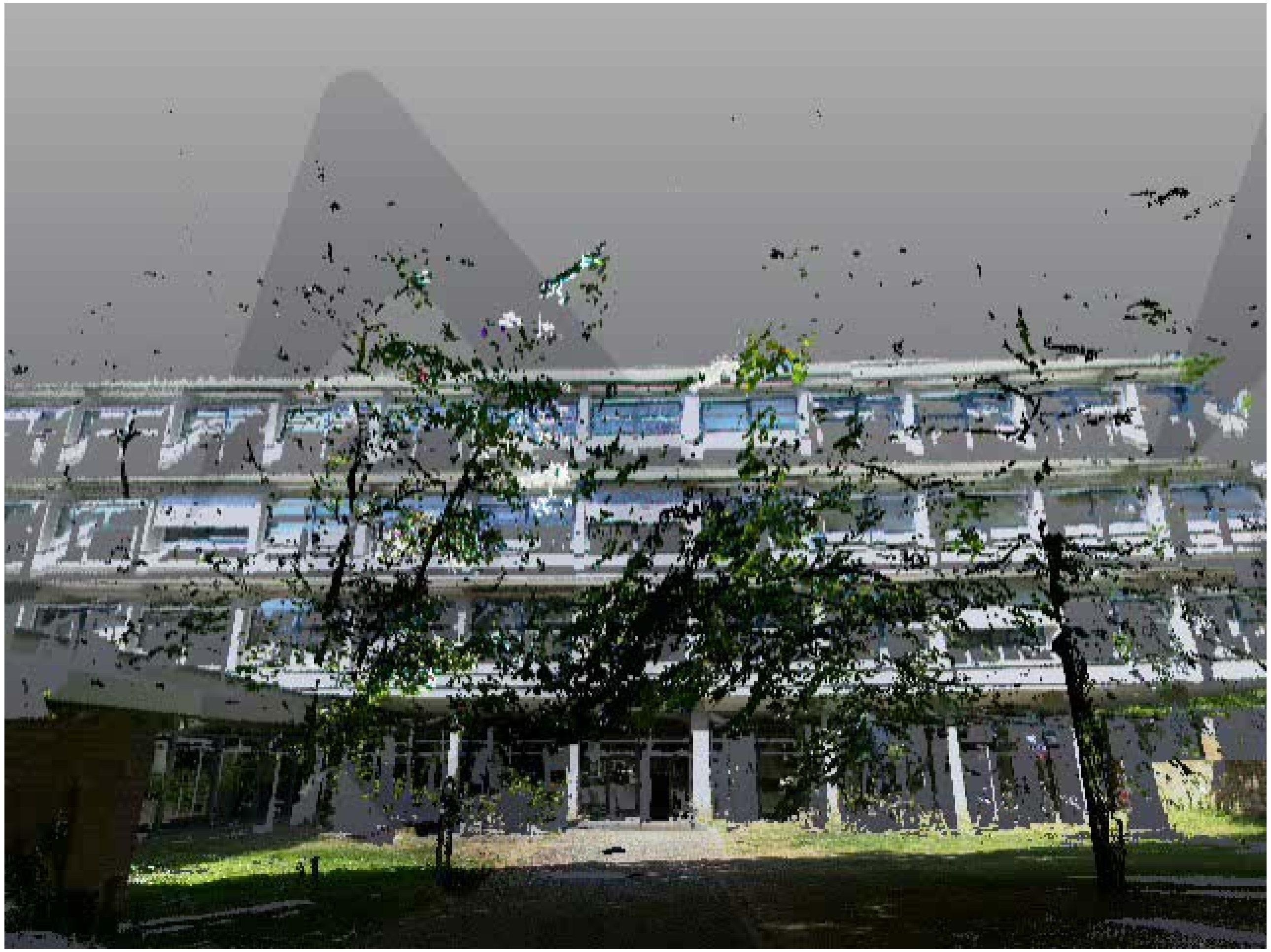




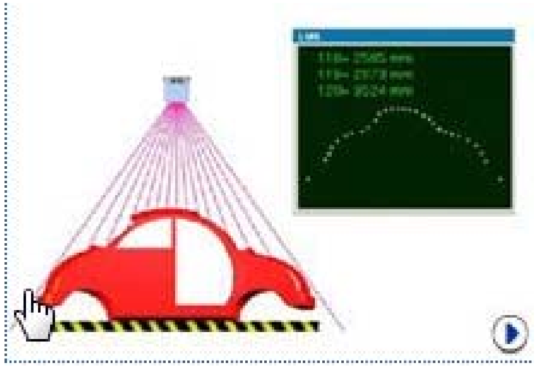
Laserradar mit Drehspiegel

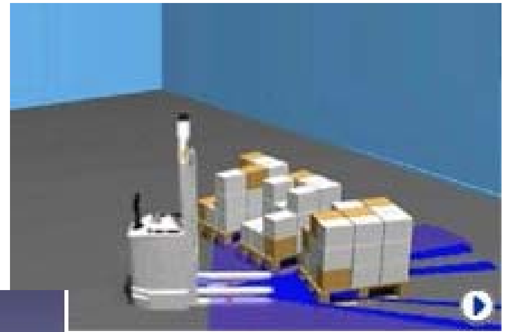


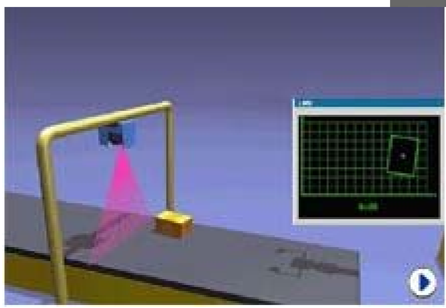
Faro 3D Scanner mit ITIV Signalverarbeitung



Sick Laser Scanner

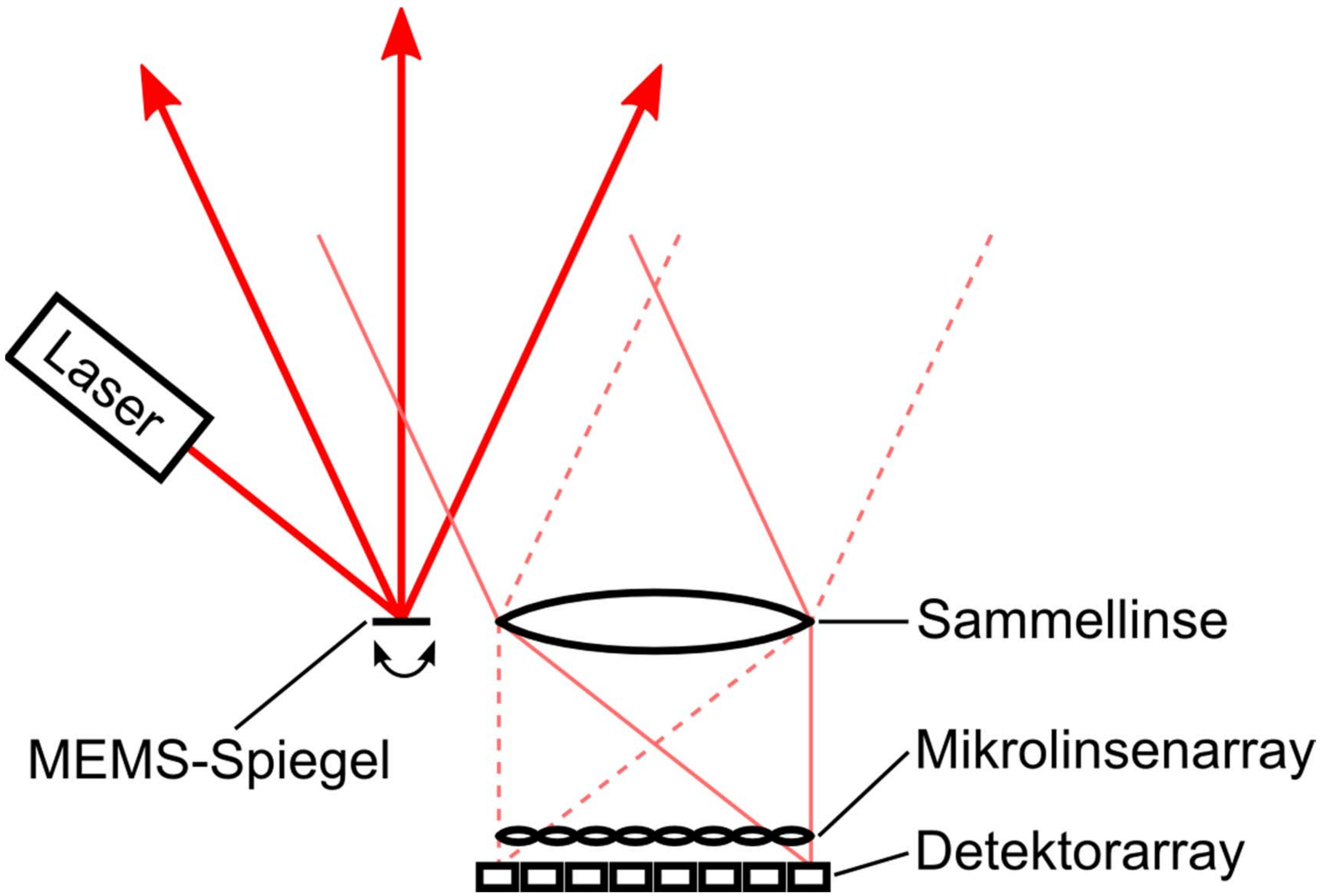




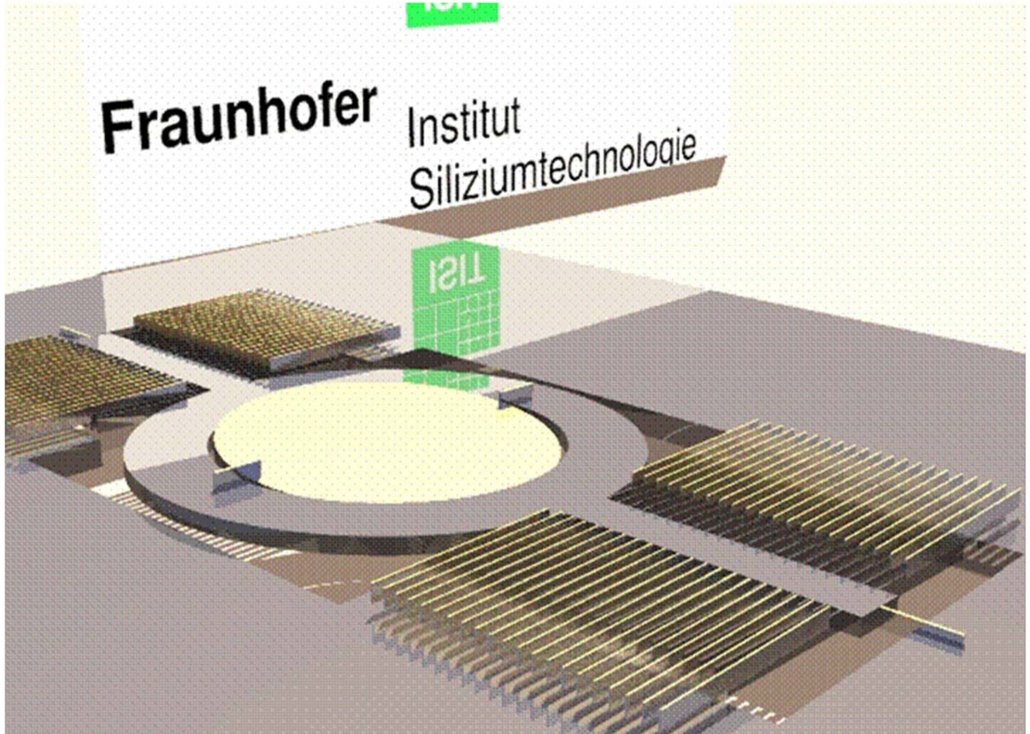


Fahrerlose Transportsysteme

Systemüberblick – Optischer Aufbau Sari



Stand der Technik – Scannende MEMS Mikrospiegel



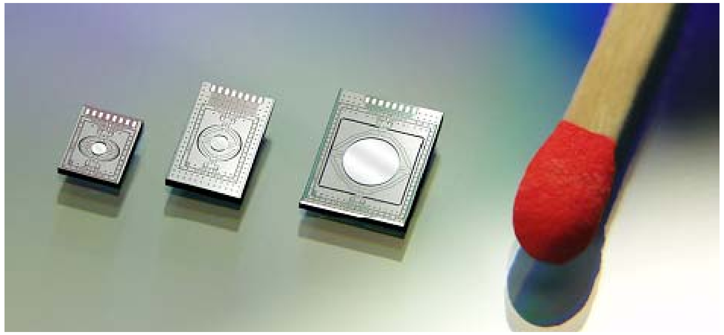
Source: FHG ISIT

- 2-Achsen Scan
- $f_{res} \approx 20$ kHz
- Spiegelgröße: Ø ≈ 1 mm
- Hohe Stoßfestigkeit (> 2000g)
- Electro-statisches Antriebsprinzip

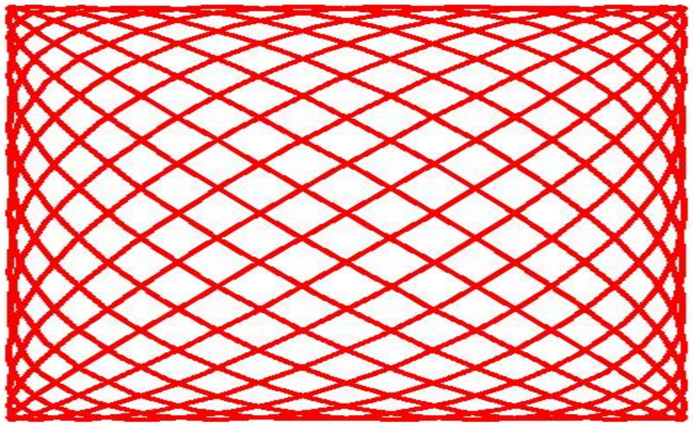
Stand der Technik – Elektrostatische Mikrospiegel

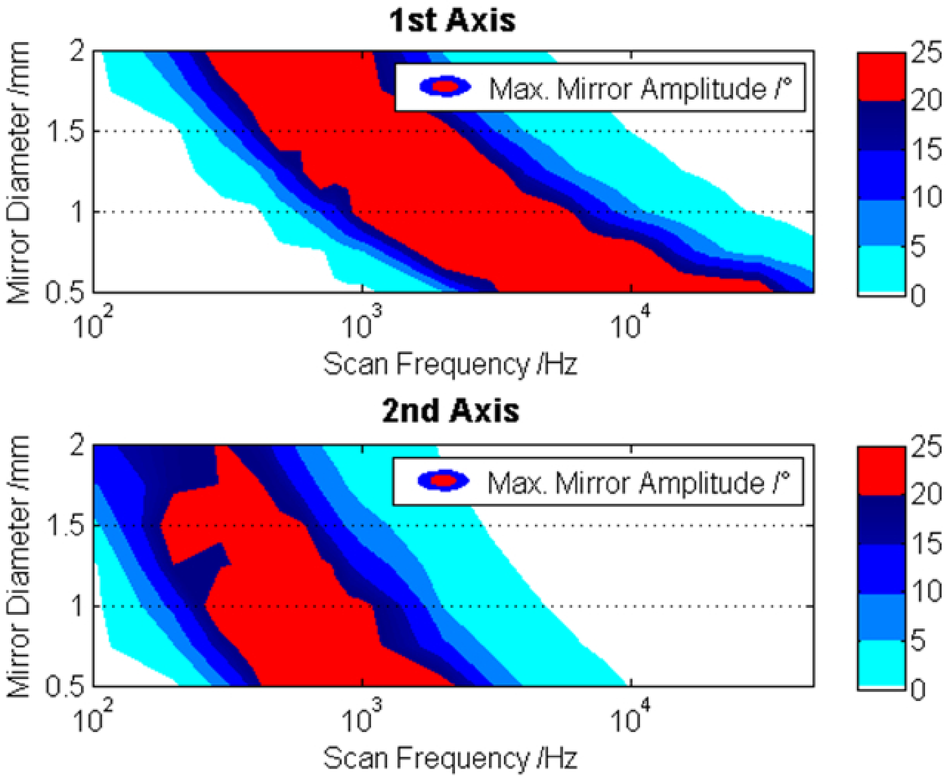
Parameter	Wertbereich
Spannung	0…100V
Resonanzfrequenz	0.1…40kHz
Max. Auslenkwinkel	+/-60°
Durchmesser	0.5…3mm

- Resonanzfrequenzen voneinander abhängig



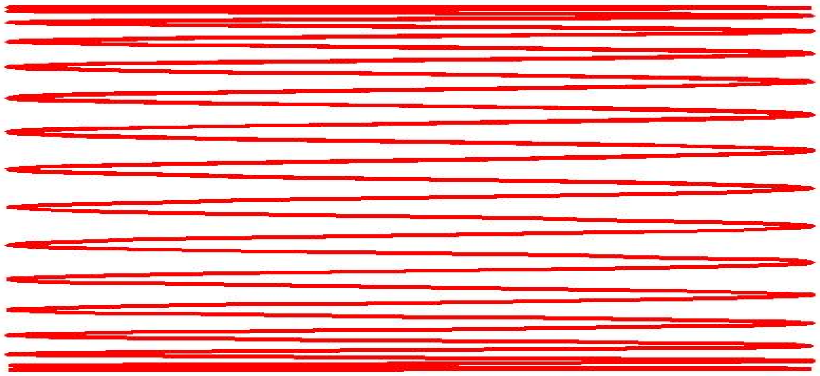
Quelle: Fraunhofer IPMS

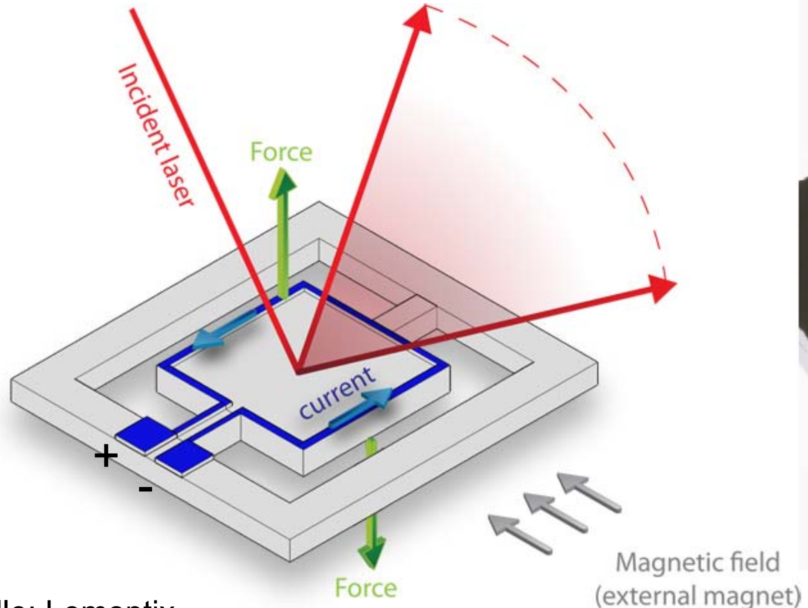




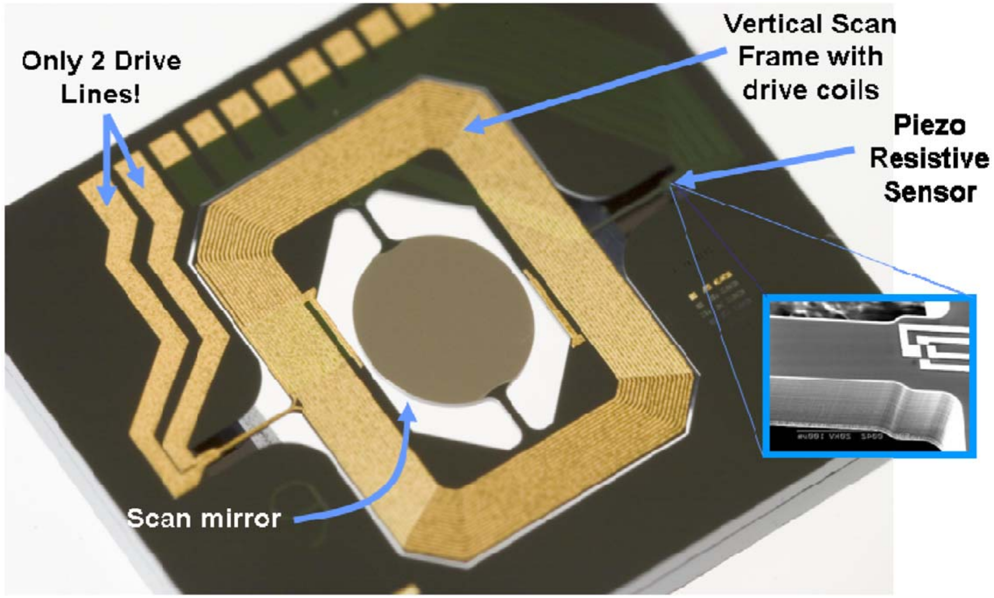
Stand der Technik – Elektrodynamische Mikrospiegel

Parameter	Wertbereich
Spannung	0…5V
Resonanzfrequenz	1…25kHz
Max. Auslenkwinkel	+/-17.5°
Durchmesser (typ.)	1mm





Quelle: Lemoptix



Quelle: Microvision

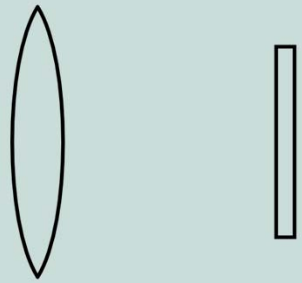
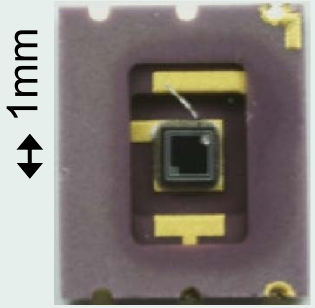
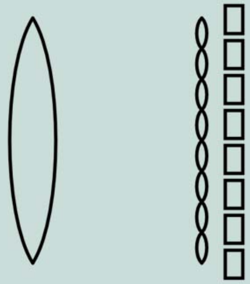
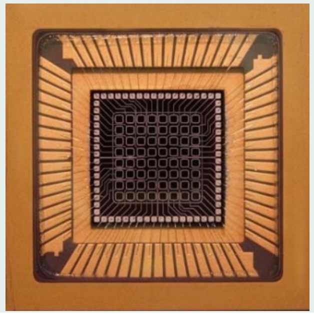
Stand der Technik – Mikrospiegel im Vergleich

Source: Microvision, Inc.

Source: FHG IPMS

	Elektro-dynamisch		Elektro-statisch	
Anregung	Elektro-magnetisch		Elektro-statisch	
2-Achsen-Scan	Ja (noch nicht erhältlich)	-	Ja	+
Scanwinkel	+/- 17.5°	-	+/- 60°	+
Anz. Hersteller	2 (Vertrieb nur 1)	-	> 5	+
Spannung	0…5V	+	0…100V	-
Scantrajektorie	Zeilenscan	+	Lissajous-Figur	-

Mögliche Detektor-Konzepte

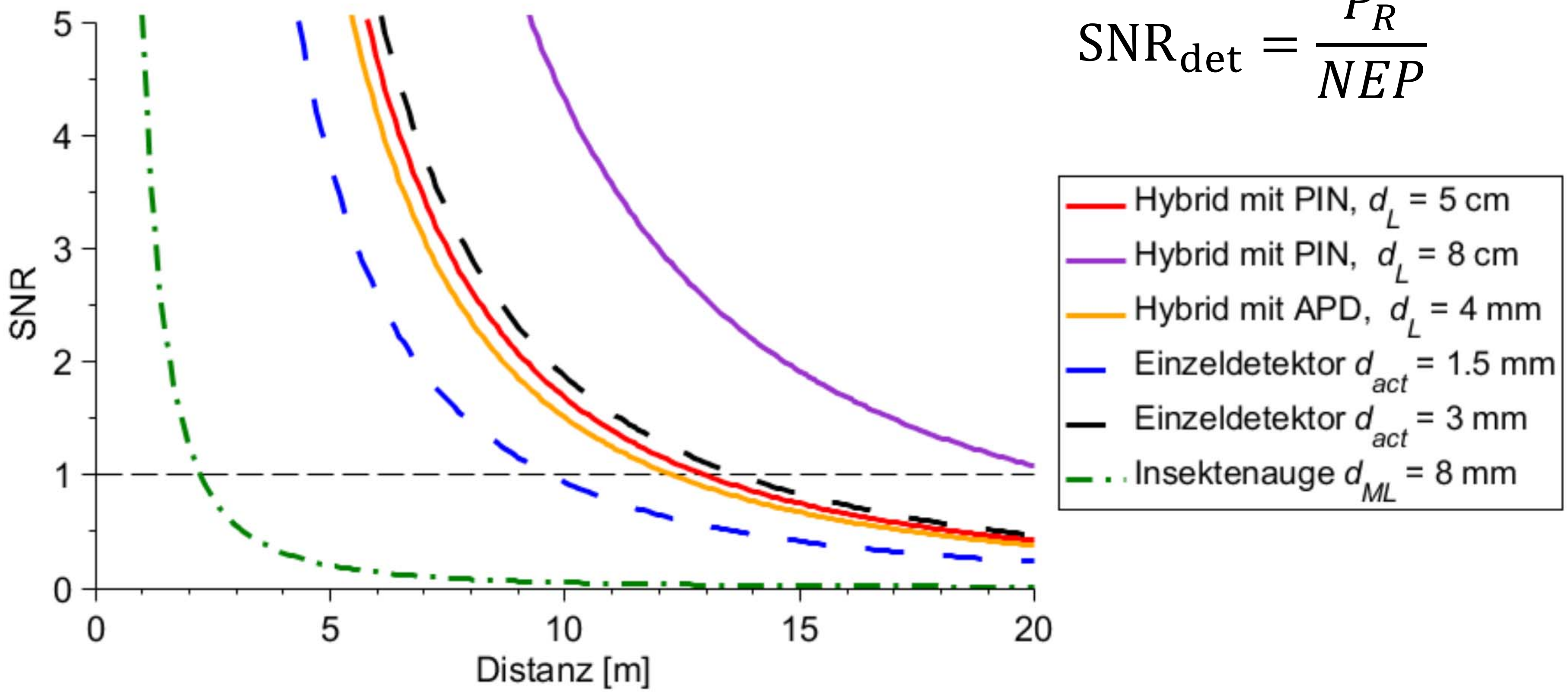
Detektorkonzept	Aufbau	Verwendeter Detektor	
1. Einzeldetektor		• Avalanche Photodiode • Akt. Fl.: ø = 3mm • f_{Cutoff} = 80 MHz • NEP ≈ $0.4 \mathrm{pW/Hz}^{1/2}$	
2. Insektenauge		• Array aus PIN-PD • Akt. Fl.: 1x1mm • f_{Cutoff} = 350 MHz • NEP ≈ $0.35 \mu\mathrm{W/Hz}^{1/2}$	
3. Hybrid		• APD-Array (8x8) • Akt. Fl.: 200x200µm • f_{Cutoff} = 175 MHz • NEP ≈ $0.3 \mathrm{pW/Hz}^{1/2}$	

SNR-Abschätzung – Detektorrauschen

Parameter	Wert
Laserleistung P_S	300mW
Reflexionsgrad ρ_{Fl}	10%
Anzahl Detektoren (Hybrid)	9x9

$$P_R = \frac{\rho_{Fl} d_L^2}{4D^2} \cdot P_S$$

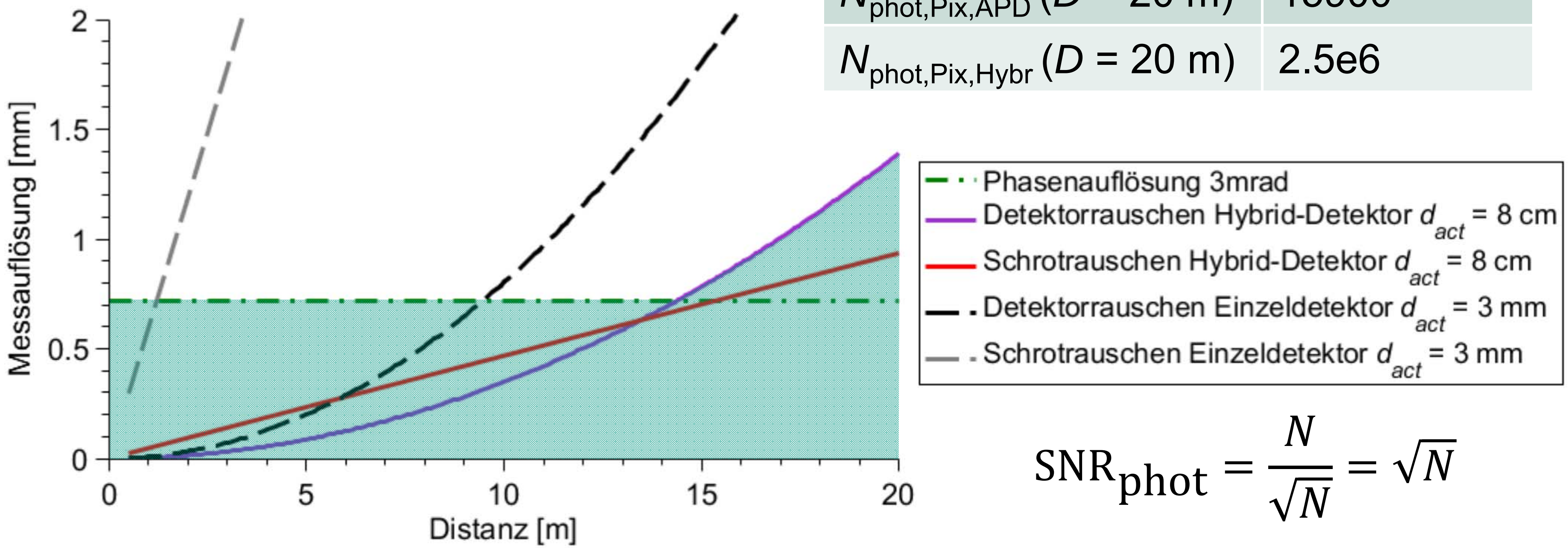
$$\mathrm{SNR}_{\mathrm{det}} = \frac{P_R}{NEP}$$



Erreichbare Messauflösung – Schrotrauschen

- Einzeldetektor durch Schrotrauschen begrenzt
- Hybrid-Detektor durch Detektorrauschen begrenzt

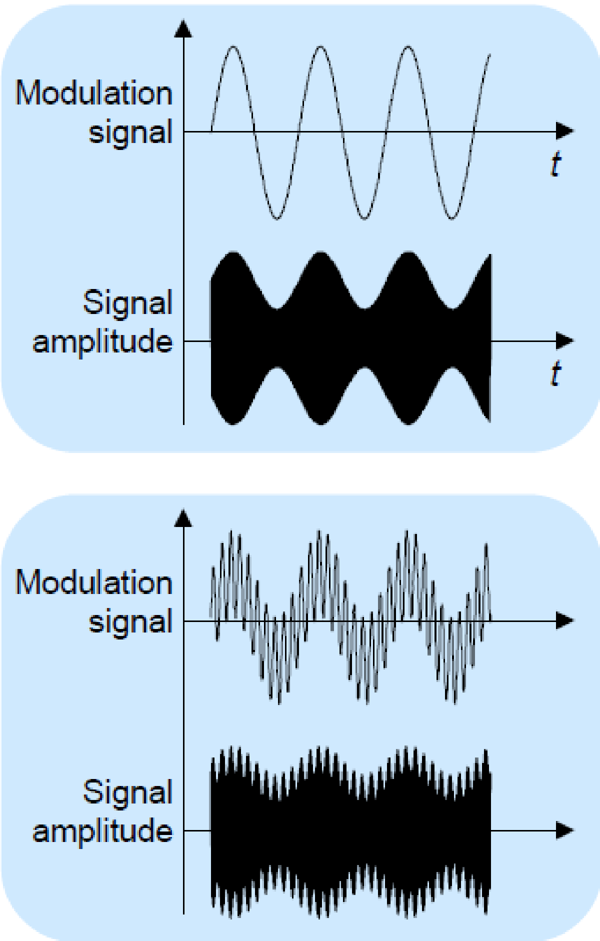
Parameter	Wert
Auflösung (Pixel)	100x100
f_{fast}	1 kHz
f_{slow}	30 Hz
T_{Pix}	1.5 µs
$N_{phot,Pix,APD}$ (D = 20 m)	15900
$N_{phot,Pix,Hybr}$ (D = 20 m)	2.5e6

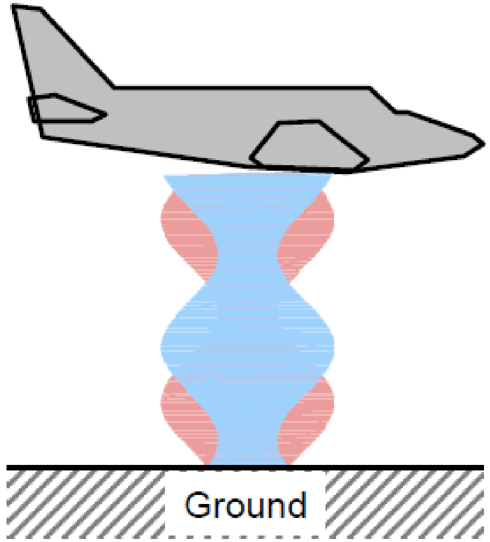


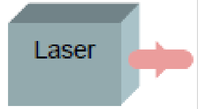
$$\mathrm{SNR}_{\mathrm{phot}} = \frac{N}{\sqrt{N}} = \sqrt{N}$$

Boden Konturvermessung

Continuous laser operation



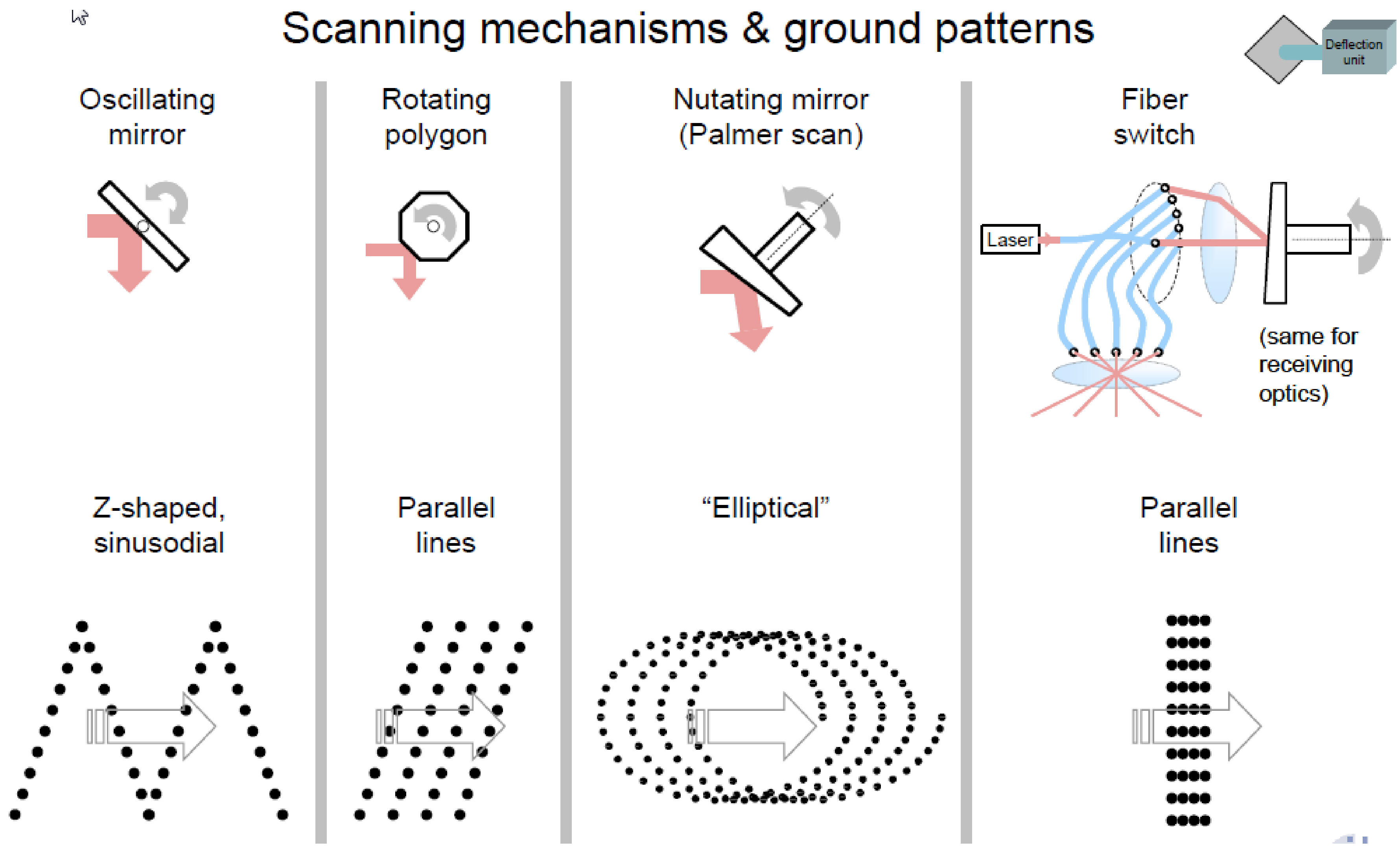




Characteristics (ScaLARS):

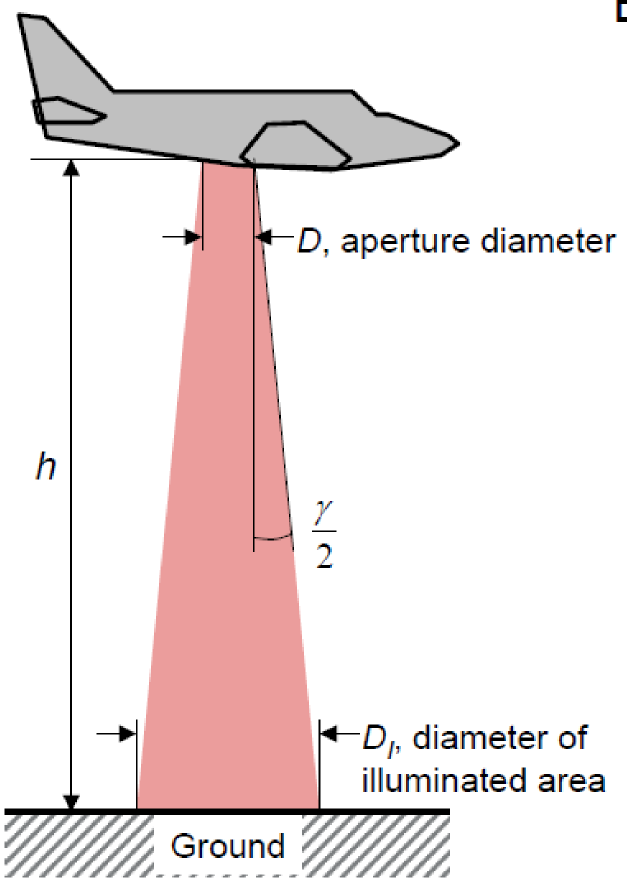
- Two modulation frequencies
  f_{high} = 10 MHz, f_{low} = 1 MHz
  → λ_{short} = 30 m, λ_{long} = 300 m
- Average power (continuous operation)
  P_{av} = 0.26 W

Scan Verfahren

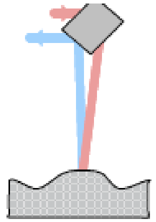


Spotgröße am Boden

Beam divergence



(not to scale)



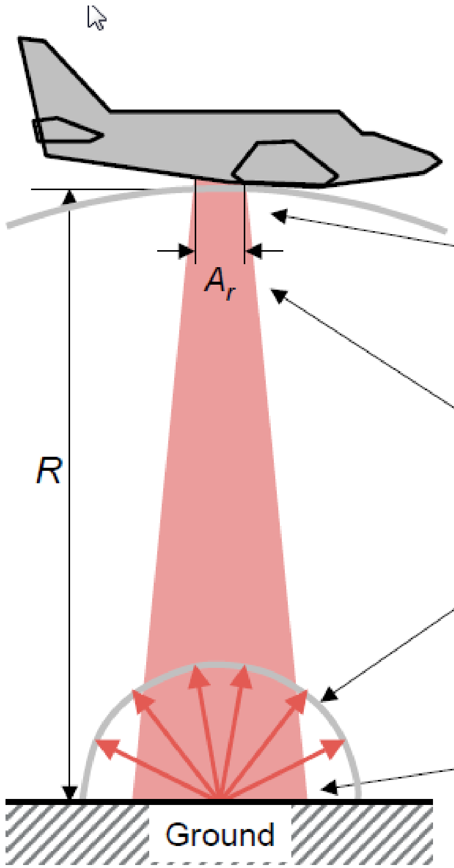
- Laser beam widens with distance
- Beam divergence γ
- Theoretical limit by diffraction $\gamma \geq 2.44 \frac{\lambda}{D}$
- Example:
  λ = 1064 nm, D = 10 cm → 0.026 mrad
- Typical values for ALS:
  γ = 0.3 – 2 mrad
- Ground spot diameter

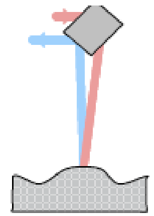
$$
\begin{aligned}
D_I &= D + 2h\tan(\gamma/2) \\
&\approx 2h\tan(\gamma/2) \\
&\approx h\gamma
\end{aligned}
$$

- Example:
  γ = 1 mrad
  → 1 m diameter @ h = 1 km flying height

Leistungsparameter

Power balance





4 - Power received:

$$P_r = \frac{A_r}{2\pi R^2} \cdot M \cdot \rho \cdot M \cdot P_T \quad = \quad \rho \frac{M^2 A_r}{2\pi R^2} \cdot P_T$$

1 - Power transmitted:

$$P_T$$

3 - Power reflected, assuming Lambertian surface:

$$\frac{\psi}{2\pi} \cdot \rho \cdot M \cdot P_T$$

2 - Power received:

$$M \cdot P_T$$

- P_T = 2000 W
- Atmospheric transmission M = 0.8
- A_r = 80 cm^2 (D_r = 10 cm)
- R = 1 km
- Reflectivity ρ = 0.5

→ $P_r = 4 \cdot 10^{-10}\, P_T$ = 800 nW

Reflektivität des Bodens

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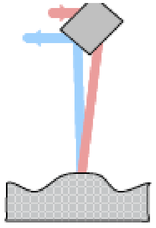
Reflectivity



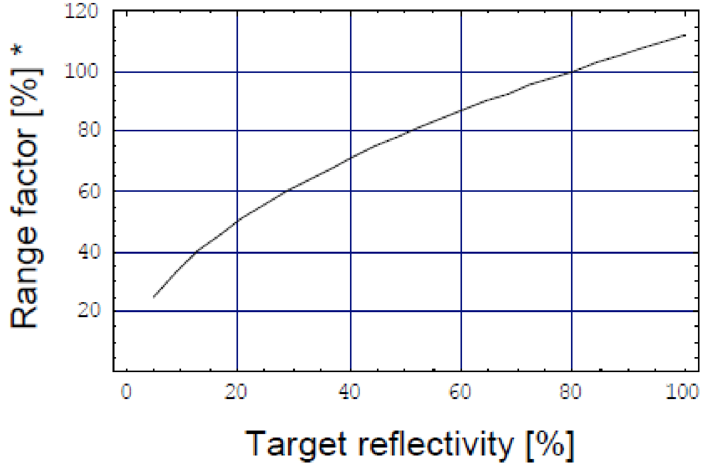
Reflectivity vs. material

MATERIAL	REFLECTIVITY @ λ = 900 nm
Dimension lumber (pine, clean, dry)	94%
Snow	80-90%
White masonry	85%
Limestone, clay	up to 75%
Deciduous trees	typ. 60%
Coniferous trees	typ. 30%
Carbonate sand (dry)	57%
Carbonate sand (wet)	41%
Beach sands, bare areas in desert	typ. 50%
Rough wood pallet (clean)	25%
Concrete, smooth	24%
Asphalt with pebbles	17%
Lava	8%
Black rubber tire wall	2%

Source: www.riegl.co.at

Range vs. reflectivity

$$P_r = \rho \frac{M^2 A_r}{2\pi R^2} \cdot P_T \quad \Rightarrow \quad R \propto \sqrt{\rho}$$



* Normalized to 100% @ 80% reflectivity