The use of an automotive 77 GHz radar as a microwave rain gauge

Silvano Bertoldo[1, 2], Claudio Lucianaz[1], Luca Bongarzone[1], Marco Allegretti[1,3]

(1) Politecnico di Torino, Department of Electronics and Telecommunications (DET), Corso Duca degli Abruzzi 24, 10129, Torino, Italy.
(2) 3ntr, Jdeal-form s.r.l, Via Montegiudeo 9, 28047, Oleggio (NO), Italy.
(3) Envisens Technologies s.r.l., Corso C. Menotti 4, 10138, Torino, Italy.

Email: *silvano.bertoldo@gmail.com*

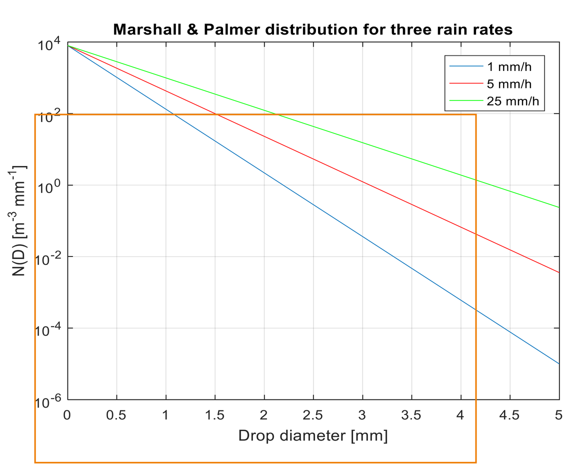
INTRODUCTION

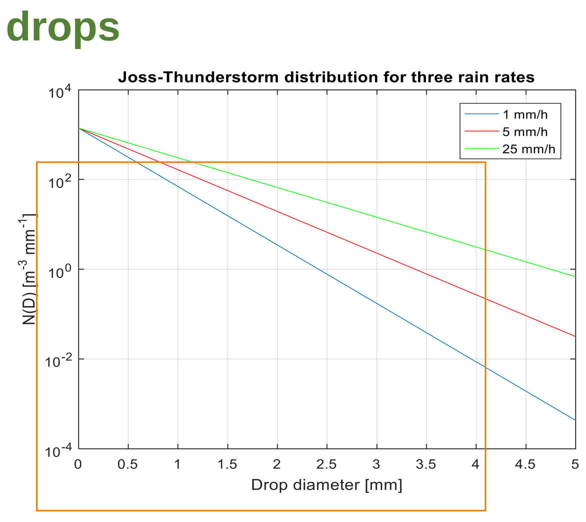
- **Automatic Cruise Control "long-range radar" operating at 77 GHz. This enables a vehicle to maintain a cruising distance from a vehicle in front (European Telecommunication Standards Institute, ETSI).**

- **Use common cruise control long-range radar operating at 77 GHz for rain monitoring and Quantitative Precipitation Estimation (QPE).**
- **This kind of mini weather radar can extend the concept of "car as sensor", in a wider view of the Internet of Things (IoT).**
- **A set of car equipped with such weather radar can constitute a capillary network for rain estimation and nowcasting operations.**

MIE SCATTERING THEORY FOR 77 GHz RADAR

Rain drops





Most of drops have a diameter < 4 mm

Radar

Radar working at

f=77 GHz
λ=~3.8 mm

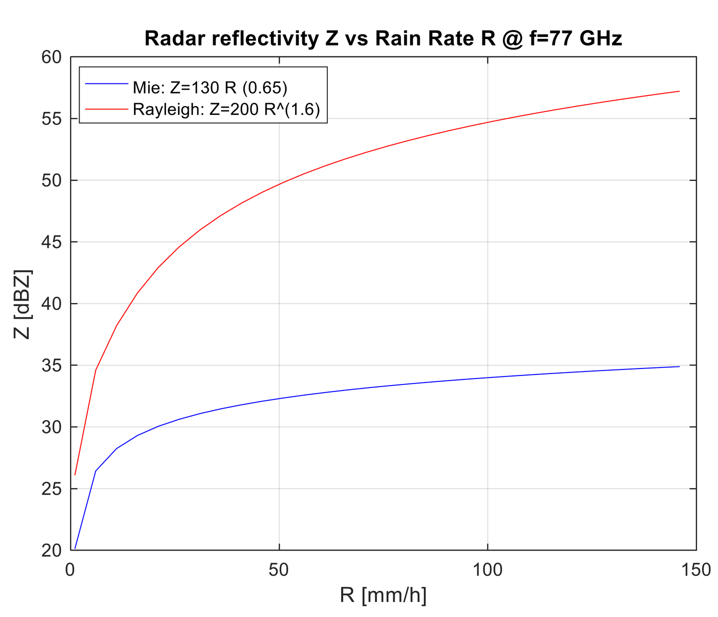
Raindrop size and λ are comparable!

Radar Reflectivity Factor *Z* for Mie Theory:

$$Z_{\text{Mie}} = \frac{\lambda^4}{\pi^5 |K|^2} \int_0^{D_{\max}} \sigma_{\text{Mie}} N(D)\, \mathrm{d}D,$$

Depend on λ^4 → ***Z [mm⁶m⁻³]=F(R [mm/h], f[Hz])***

New Z-R equation properly determined!



$Z(77\ GHz) = 130\ R^{0.65}$

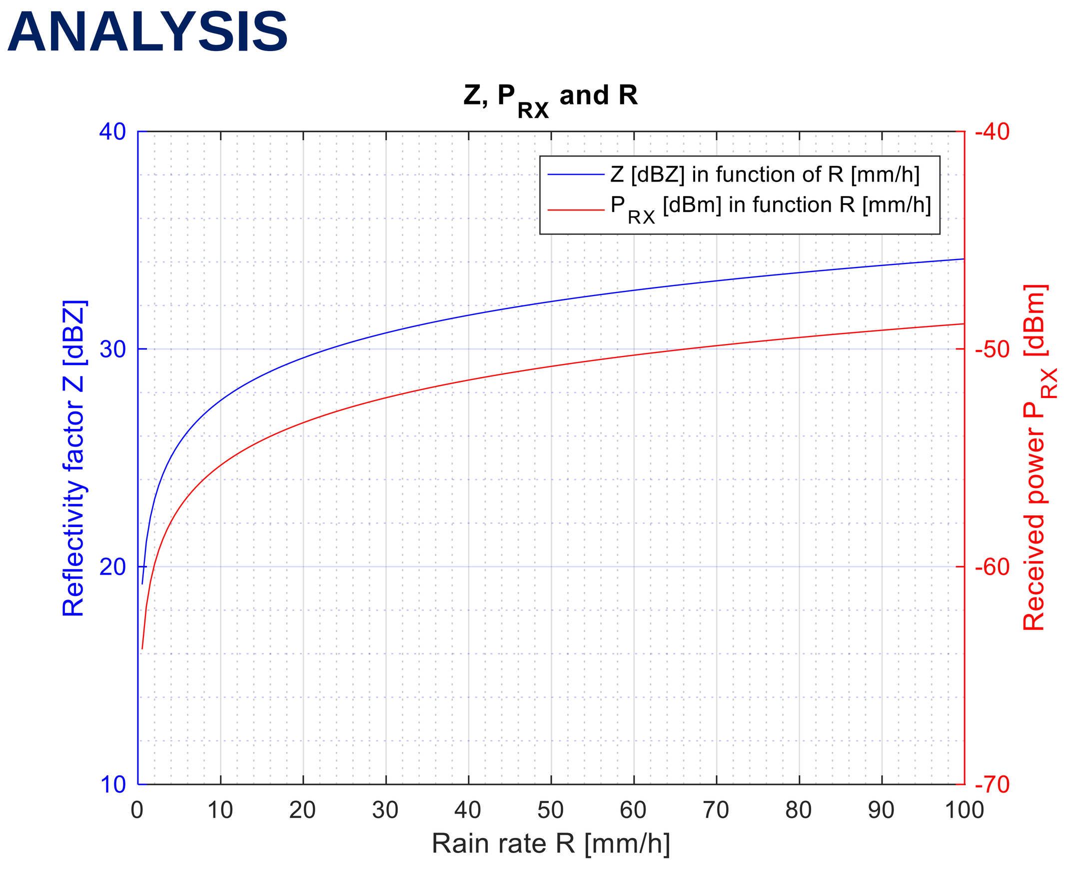
The use of Rayleigh approximation with a 77 GHz radar used for meteorological purposes may lead up to a 20 dB of underestimation of the radar reflectivity factor *Z*!

RADAR CONSTANT EVALUATION

$$P_r = \frac{P_t * Konst * Z}{R^2} \qquad Konst = \frac{c\, G_r G_t \pi^3 \theta_{3dB} \varphi_{3dB}}{1024\, BW \lambda^2 \ln 2} L^2 K^2$$

$Konst\,|_{db}$ **= ~ 68 dB**

SENSITIVITY ANALYSIS

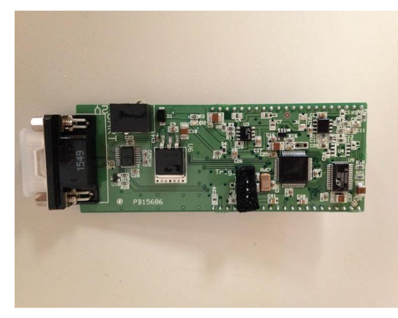


Radar reflectivity factor (*Z*) and Received Power (*P_{RX}*) at a maximun distance of 50 m in function of rain rate *R*.

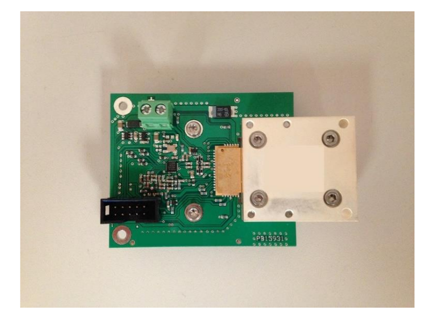
Useful dynamic: 13 dB for R = [1 – 50] mm/h

77 GHz RADAR SPECIFICATIONS

RADAR PARAMETER	VALUE
Nominal Transmitted Power (P_{TX})	4 dBm
Operational Frequencies	76 - 77 GHz
Sweep Time (T_s)	75 ms
Chirp Bandiwidth (*BW*)	1 GHz
Transmitted Waveform	Sawtooth
Radar Type	FMCW



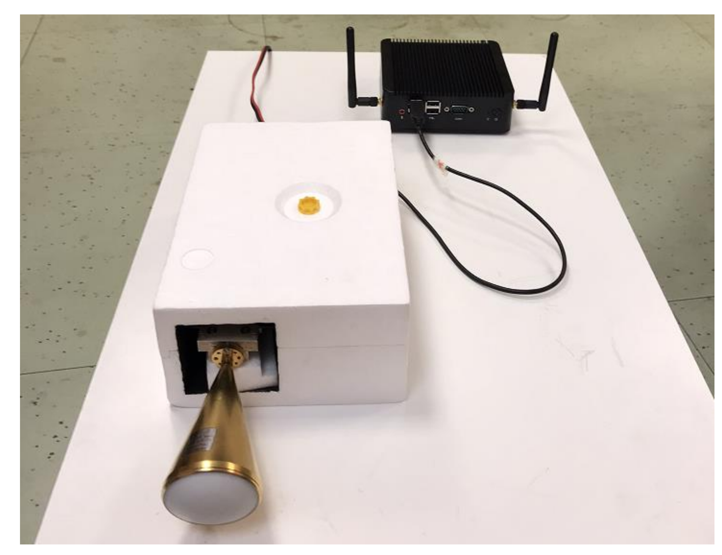
Siversima CO1000A/00 Power and controller board



Siversima RS3400W/04 77 GHz radar sensor

ANTENNA PARAMETER	VALUE
Gain (G_t)	28 dB
Length (*L*)	40 mm
Diameter (*D*)	28 mm

Antenna ELVA-1 SLHA-W



PRELIMINARY RESULTS

Acquisition procedure

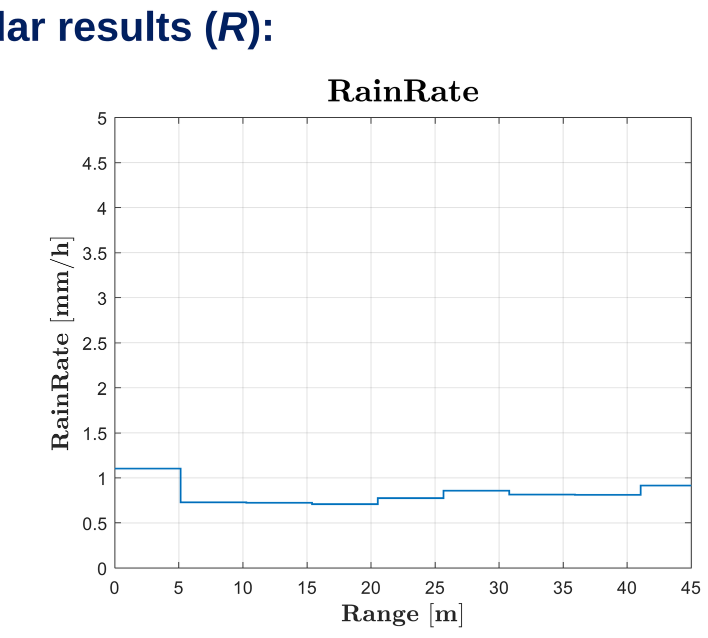
- **Acquisition of a single spectrum: average on 30 consecutive sweeps.**
- **1 acquisition every T_{ACQ} = 30 seconds**
- **Rain rate spectrum based on the average of N spectra acquired during $T_{RAINRATE}$ = 1 min ($N = T_{RAINRATE} / T_{ACQ}$).**
- **Spatial average of rain over 5 m space interval.**
- **Total acquisition time T_{RAIN} = 1 hour → Computation of cumulated rain.**

Priliminary validation procedure

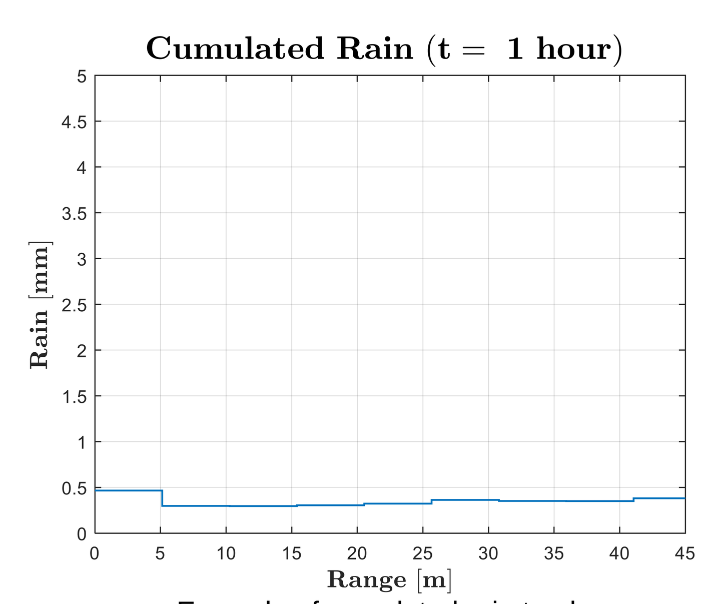
- **Acquisition of rain measuremennt of a co-located rain gauge (G).**
- **Computing the bias considering all the values of cumulated rain corresponding to each of the M spatial interval of 5 m (R_i)** $BIAS = \frac{\sum_{i=1}^{M} R_i}{M \cdot G}$

6th November 2017

77 GHz radar results (*R*):



Example of rain rate track acquired after $T_{RAINRATE}$



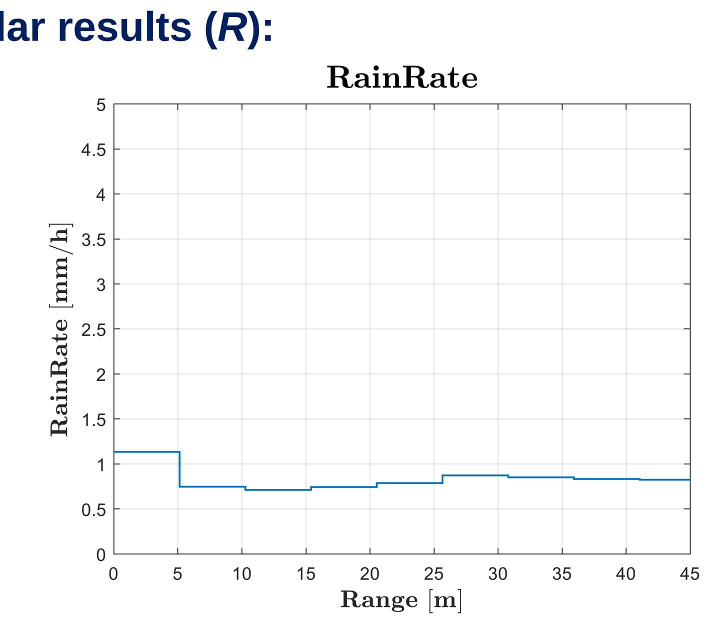
Example of cumulated rain track

Rain gauge data (*G*):
Cumulated rain 10 am – 11 am: 1.1 mm

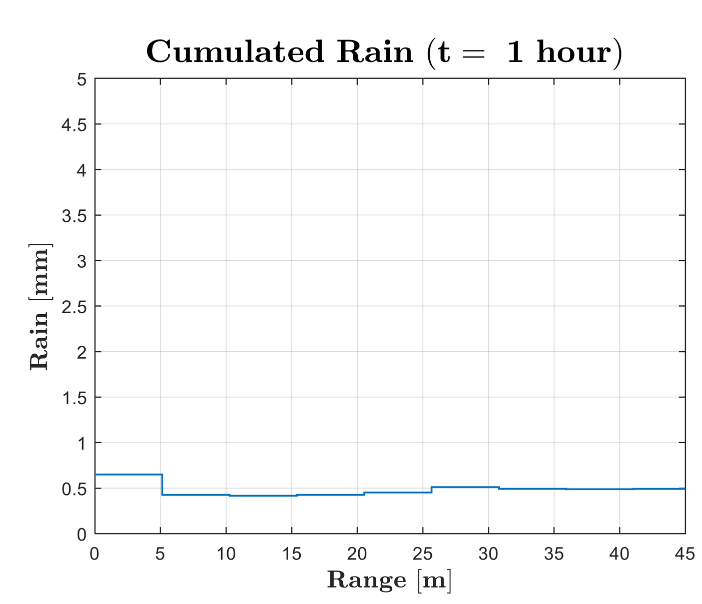
***BIAS*=0.35**
Radar underestimation of - 4.5 dB

9th January 2018

77 GHz radar results (*R*):



Example of rain rate track acquired after $T_{RAINRATE}$



Example of cumulated rain track

Rain gauge data (*G*):
Cumulated rain 9.30 am – 10.30 am: 1.6 mm

***BIAS*=0.32**
Radar underestimation of - 4.9 dB