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

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A car can be thought as a moving integrated weather sensor since it can provide meteorological information exploiting the sensors installed on board. Among these sensors there is a number of radar for variuous purposes including collision avoidance and automatic cruise control.

The European Telecommunications Standards Institute (ETSI) defines the frequency band of 77 GHz (W-band) as the one dedicated to automatic cruise control long-range radars. We conducted a research and a made feasibility analysis to demonstrate that this kind of systems can be used also as short range weather radars and/or microwave rain gauges.

To study the behavior of a 77 GHz meteorological radar, since the raindrop size are comparable to the wavelength, it is necessary to use the general Mie scattering theory. According to the Mie formulation, the radar reflectivity factor Z is defined as a function of the wavelength on the opposite of Rayleigh approximation in which is frequency independent. The problem is that the use of Rayleigh approximation lead to an always larger underestimation of rain. At 77 GHz such underestimation is up to 20 dB which can be avoided with the full Mie theory (Figure 1). The crucial derivation of the most suited relation between the radar reflectivity factor Z and rainfall rate R (Z-R equation) is therefore necessary to achieve the best Quantitative Precipitation Estimation (QPE) possible. Making the use of Mie scattering formulation from the classical electromagnetic theory and considering different radar working frequencies, the backscattering efficiency and the radar reflectivity factor were derived from a wide range of rain rate using specific numerical routines. By knowing the rain rate and the corresponding reflectivity factor it was possible to derive the coefficients of the Z-R equation for each frequency with the least square method and to obtain the best coefficients for each frequency. Results are presented in details in [1] and [2] and the obtained Z-R relationship is reported in the following eq. (1).

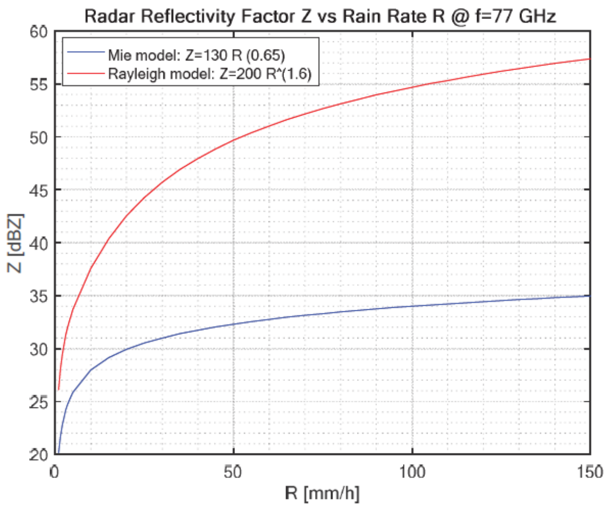

Figure 1. Example of underestimation of rain using a common Z-R equation obtained with Rayleigh scattering theory with respect to the one obtained with Mie theory considering the Marshall and Palmer DSD [14]. The underestimation varies from 5 dB to more than 20 dB in term of Z, with the increasing of rain rate R measured in [mm/h].

$$Z(77\ GHz) = 130R^{0.65} \qquad \text{eq. (1)}$$

In order to use a 77 GHz radar as a short range weather radar it is also necessary to compute both atmospheric attenuation and absorption. They were estimated taking into account the proper ITU-T recommendations, in paricular “Recommendation ITU-R P.838-3 – Specific attenuation model for rain for use in prediction methods” and “Recommendation ITU-R P.676-6 – Attenuation by atmospheric gases”.

Functional requirements in adapting automatic cruise control long-range radar to a microwave rain gauge were analyzed in details and presented the first time in 2017 in [3], and then completed in [1] and [2]. Hence, the technical specifications were determined in order to meet the functional requirements and to use a 77 GHz radar as a microwave raingague. They are summarized in the following Table (1) and (2).

Table 1. Functional specifications

Specification	**Value**
Max operative range	100 m
Range resolution	5-10 m
Sensitivity	Rain rate R=0.5 mm/h at 100 m
Operative frequency	77 GHz (W-band)
Polarization*	2 orthogonal polarization (V – H)
Radar technology	FMCW

* Dual polarization is not mandatory. The radar can be also used with a single polarization, especially considering the components available on the market for automotive applications

Table 2. Technical specifications

Specification	**Value**
Sensitivity	0.5 mm/h at 100 m (20 dBZ at 100 m)
Noise figure	15 dB
Receiver bandwidth	< 20 MHz
SNR	3 dB
Transmitted power	6 dBm
Radar constant	66 dB
Antennas (Gain and HPBW)	30 dB – 20 °
Chirp bandwidth	< 15 MHz
Sweep Time	< 20 ms

The study was completed by using a commercial prototype of W-band radar used to develop cars applications and making some experimental measurements during rain events. They show that it is possible to use W-band radar for monitoring weather events. A good Quantitative Precipitation Estimation (QPE) can be achieved with an acceptable approximation. The prototypal 77 GHz radar underestimates the rain of about 4 dB, a quantity that can be properly compensated using proper calibration procedures [4].
With our research, we think that cars already equipped with the automatic cruise control “long-range radar” operating at 77 GHz can use that system also for weather moniroting purposes. In future, acquired and measured data can be elaborated with different parallel processing chains in order to allow cars to become also “moving rain gauge”.

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