# Developing a Low cost C-band FMCW Microwave Areal Rain Gauge – MARG

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## 1 Introduction

The estimation of the rainfall over an area is a difficult task. The rainfall is discontinuous in space and in time because of having large natural variability unlike many other meteorological parameters. The widely used method for getting relatively accurate precipitation data over land is the combination of radar rainfall and rain gauge data. The typically used radar data is coming from long-range weather radars operating in C or S band or from X band short range radars. Using such radar data we are facing several constraints:

- long range weather radars operating on C and S band and their networks are expensive and having high operational costs also but not supplying accurate precipitation data with high temporal and spatial resolution at longer ranges
- low priced X band MINI radars are giving unreliable data in moderate and heavy precipitation because of the strong attenuation and also in stratiform rain because of very big vertical beam if they hare having slotted waveguide antennas,
- Doppler dual polarized X band MINI radars are expensive and having high operation cost also.
- X band measurements can be blocked in heavy thunderstorm because of the attenuation.

Based on present radar technologies and keeping in mind the end user needs, we decided to built up a concept for an innovative measurement device so called Microwave Areal Rain Gauge – MARG using for short ranges to reach better measurement performances than existing low cost X band radars.

## 2 . MARG Concept

### *1.1 Selection of Wavelength*

It is well known that the radar reflectivity is inversely proportional to the fourth power of the wavelength. At shorter wavelength the radar will be more sensitive and smaller antenna and lower transmitter power will be required. Therefore, the use of the X band is so popular but attenuation of the microwaves in precipitation has a great importance. In heavy rainfall (50 mm/h) the attenuation will be so high that the X band radars can detect the first edges of rainy areas or the measurement can be totally blocked even at short ranges, see Figure 1.

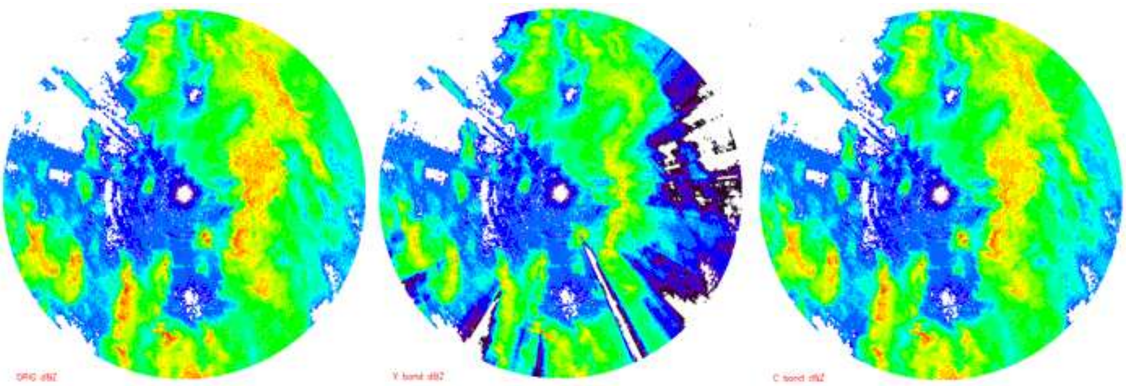

*Figure 1. The impact of the attenuation calculated for X band (middle) and C band (right) using a reference dBZ distribution (left) for 50-55 dBZ cells up to 30 km ranges*

There are some algorithms for attenuation correction but they are having important drawbacks. The dual polarization methods need more sophisticated and expensive radar systems, see HYDRIX., METEOR 50DX; CASA and the combination of reflectivity's using overlapping measurement ranges need more radars deployed on a given area. Keeping in mind our goal to develop a simple and cost effective solution for wide range of rainfall intensities the C band have been MARG .

### *1.2 Selection of Antenna Type and Beam with*

The beam with and type of antenna is big issue for MINI radar concepts. To reach the minimum geometrical sizes and compactness we need for as small as possible antenna solution. Before choosing the antenna type and its geometrical properties we analyzed the impact of the horizontal and vertical smoothing of different antenna types and beam with. Avoiding the unreliability and possible misinterpreting of weather radar equation the dual parabolic antenna solution has been chosen for MARG system.

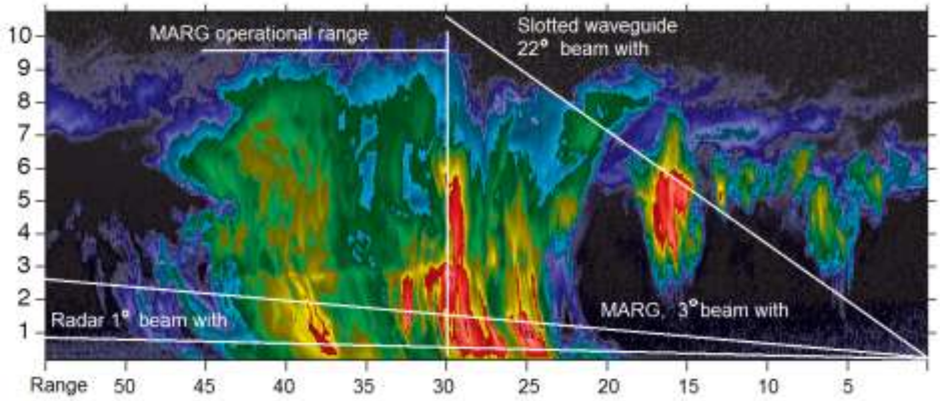


*Figure 2. Illustration of different beam with on a virtual RHI section. The background picture was taken from presentation I. Zawadzki (2008)*

To make a compromise between the targeted space resolution and the overall cost of MARG system the dual parabolic antenna with size of 1.5 meters was selected for MARG resulting 3 degree beam width in horizontal and in vertical. See Figure 2.

### *1.3 Selection of FMCW Operation*

The weakly backscattering meteorological objects are providing enough power for detection when they are continuously illuminated by far less transmitted signal energy then conventional impulse radars. Using FMCW operation the power factor is about 1,000 that means we need only for some ten watts TX power instead of kilowatts. As a result solid state electronics can be applied in all modules and coaxial cables instead of wave guides causing the FMCW radars to be much cheaper than magnetron based pulsed radars. But they are needs more sophisticated signal processing for getting range, reflectivity and velocity information using FM transmitted signals doing continuous spectral processing of the received signal. To retrieve both distance and velocity information from the weather targets, a two stage or 2D-FFT real time implementation is necessary. The first stage of the FFT is applied on the echo samples from one frequency sweep, and the second stage on the range cell results of several consecutive sweep periods

## 3 Specifications of MARG

### *2.1 Main Operational Characteristics*

Based on the MARG concept by *F. Dombai* a Consortium was organized and a project proposal was formulated to develop a high resolution, low cost, microwave, short range precipitation measurement system called MARG. The MARG sensor technical specification was derived from the user needs Consortium SME partners with consultancies with RTD partners. The main operational characteristics of MARG system are selected as follows:

- measurement distance up to 30 km and for all derived parameters with 100 m range resolutions, 1 min cycles
- tunable carrier frequency at C band (5.6 GHz),
- FM/CW with Doppler signal processing for high grade ground clutter rejection,
- Configurable FMCW parameters (sweep duration, frequency span, range resolution, number of range bins, number of sweeps for integration, unambiguous radial velocity)
- Z-R conversion with adjustable parameters using rain types, identification of rain types based on echo structures
- minimum rain rate at 30 km 0.2 / 0.5 mm/h
- accuracy: reflectivity measurement errors less then 0.5 dBZ
- self-calibration with ground clutter, with nearby disdrometer (optional)
- providing QPE using additional rain gauges or disdrometers (1, 3, 6, 12, 24 hour totals)
- full automatic operation, WEB based user services
- only horizontal scans at adjustable elevation

### *2.2 Estimation of Minimum Detectable Signal*

The received average echo power at the radar receiver can be calculated according to the weather radar equation:

$$P_r = P_t \frac{\pi^3 |K_0|^2}{512 \cdot \ln 2} \cdot \frac{G^2 \theta_H \theta_V}{\Delta R \lambda^2 L_i} \cdot \frac{Z}{R^2 L_{(R)}^2},$$

where $P_r$ and $P_t$ denote the received and transmitted power, $G^2$ the two way antenna gain (assuming both antennas having the same gain), $\theta$ the horizontal and vertical beamwidth, $\Delta R$ the range resolution, $\lambda$ the wave length, $R$ the distance of the range cell, $L$ internal and external (two way) losses, and $Z$ the reflectivity. From the detailed technical specification of MARG we are having

*Operating frequency*: 5600 – 5650 MHz
*Targeted output power*: 20 W
*Antenna*: two paraboloid 1.2 m, 36 dB gain
*Beamwidth*: 3 degree
*Bandwidth*: 3 MHz for range gates of 50 m
*Noise figure*: estimated noise figure of 3-4 dB

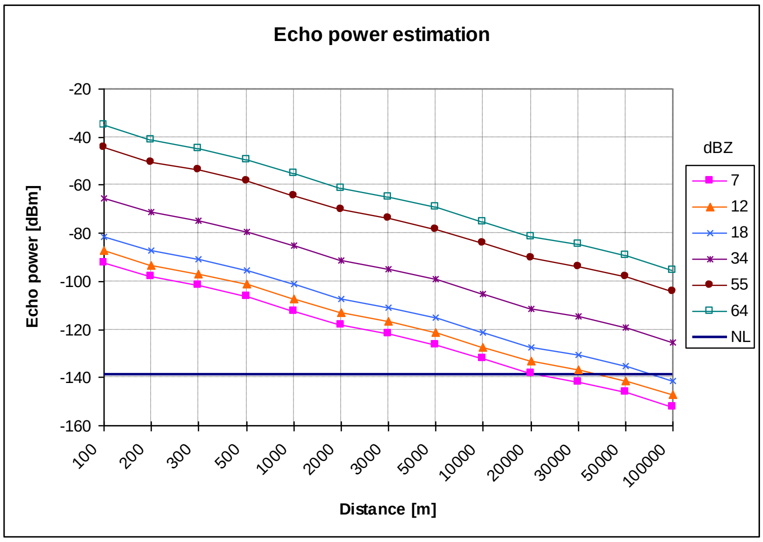


*Figure 3. Estimated echo power over range for different radar reflecitivies in comparison to noise level with MARG specification . Sensitivity is 7 dBZ at 20 km.*

## 4 . MARG System Overview

### *4.1. MARG Radar Sensor and Signal Processing*

The MARG radar sensor main modules are two parabolic antennas with rotational mechanics end electronics, radar frontend and network interface and control electronics. See Figure 3. for the proposed MARG structure. To achieve sufficient isolation (> 50 dB) between the transmitter and receiver modules, and to avoid using complex and expensive microwave components, two parabolic antennas will be used to transmit and receive the FMCW signal. The RF front end will operate in the C-band at 5.6 GHz. At this frequency, the proposed 3˚ half power beam width and 36 dB antenna gain can be achieved using an antenna with a diameter of minimum 1.2 meters. The exact dimension will be a function of the shape of the reflector and the illumination pattern of the feed. To collect enough information from each spatial segment the rotation speed will be set at > 30 seconds per rotation. The maximal output power will be 20W continuous, which will result in a detection range of 20–30 km

*Radar Frontend* contains three main modules: *a digital transceiver, a high power amplifier and a low-noise receiver*. The core module *digital transceiver* module is working on intermediate frequency IF . This will generate the modulated radar signals to be linked to a separate transmitter module (HPA), where the signal will be converted to the radio frequency (RF) domain, and amplified to reach the required level of power at the antenna output. The transmitter module will include monitoring, protection, and control circuits that can measure transmitted and reflected power levels, and adjust the amplifier gain. On the receiving side MARG will contain a *low-noise amplifier*, to allow detection of very low signals. Radio signals will be converted to an IF, before being sent to the *digital transceiver*.

The *digital transceiver* is the primary radar signal processing subsystem of MARG. It will be based on a single digital IF-transceiver board, which will be capable of IF sampling, digital I/Q demodulation, and direct generation of digitally modulated I/Q signals at IF. This board will include analog-to-digital and digital-to-analog converters (ADC and DAC), and programmable DSP and microcontroller cores. A dual stage FFT processing scheme implemented in an FPGA is used to provide range and velocity information in real-time. The *digital transceiver* will consist of an *analog IF to/from digital conversion linked to an FPGA*. The FPGA is a programmable device and will be used to implement various building blocks of digital radar functions, such as demodulation or synthesizing of modulation signals and analyze the signal and retrieve echo properties. An additional general-purpose processing unit (with memory and a standard network interface) will be included in the MARG system, which will allow for implementation of control and system interface software.

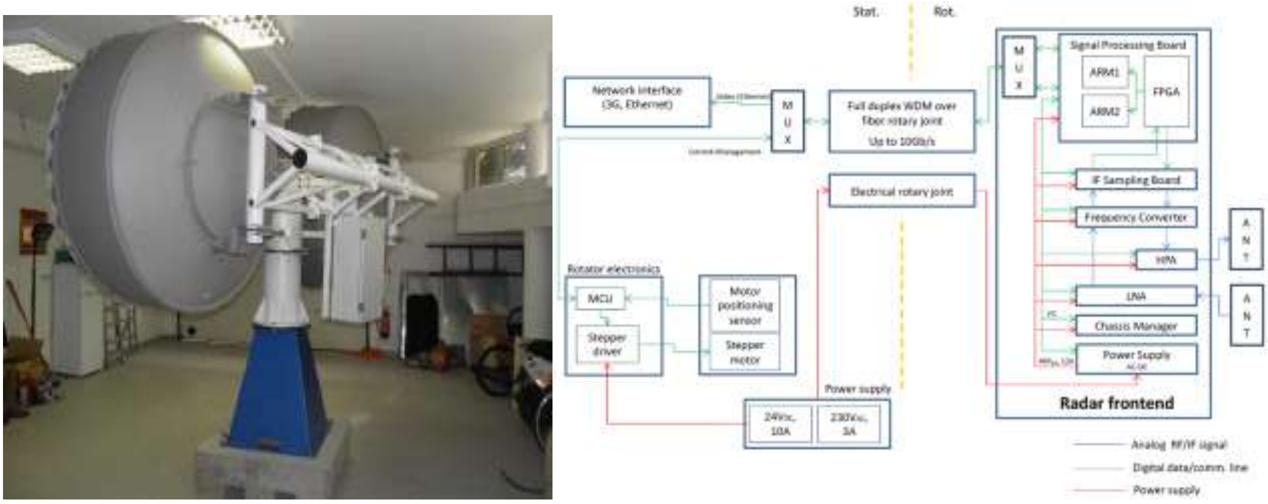


*Figure 4. The MARG prototype schematics (right) and antenna structure with Frontend box (left)*

### *4.2. Quantitative Percipitation Estimates in MARG System*

Quantitative estimation of rainfall from radar observations is a complex process. The long time established *reflectivity-based* method is the standard means to derive rainfall intensity data from radar measurements. More recently, research institutions have developed *dual polarization (DP)* methods, but most operational weather radar systems(~98%) still use the *reflectivity* method. With conventional single polarization radar in each range bin the rainfall rate *RR* is derived from the radar reflectivity *Z* using the well known Marshal -Palmer Z-R relationship. The algorithms for MARG *optimal real time* QPE will be developed considering measured radar reflectivity radar and ancillary data (i.e. rain-gauges, disdrometers).

At the first step the MARG will use adjustable parameters for the exponential Z-R relationship. The parameters will depend on the rainfall types as stratiform or convective. In order to classify whether we are observing stratiform or convective precipitation or different parts of the same precipitation system the algorithm proposed by Steiner in his paper (Steiner et al, 1995) will be implemented in the MARG QPE. With MARG it is possible to collect a 360 degree radar scan every approximately 30 seconds: we can therefore apply Steiner's algorithm to each scan.

Later on when disdrometer and/or rainguages are connected to MARG system the basic QPE results will be refined using rainfall rate and precipitation data from these devices. The disdrometer data will be used mainly for calibration and for proper selection of parameters of Marshall- Palmer equation. If rainguages data are also available the user can decide to use different spatialization methods for adjustment of radar rainfall data of MARG. Users can select to use a very simple method (type=1, in which the spatialized assessment factor is simply the median value of the assessment factors relevant to the rain-gauges in which precipitation is recorded), or Kriging, and spefically Ordinary Kriging (type=2) or Universal Kriging (type=3). However, only the type=1 method will be used if the number of rain-gauges recording precipitation does not exceed a minimum value. In Ordinary Kriging, the weights are calculated based on a semivariogram function, and a linear system of equations, which yields the "best linear unbiased estimator" (BLUE)

The MARG QPE algorithm will be implemented in two versions: a "basic" QPE product available directly at the radar platform, and the “full” QPE, comprising the integration of the rain-gauges and the disdrometer, which will necessarily run on a separate machine. The “basic” QPE algorithm will provide a simple polar to Cartesian conversion and apply a fixed/adjusted Z-R relation to generate a georeferenced product (geotiff) which will be then easy to display everywhere

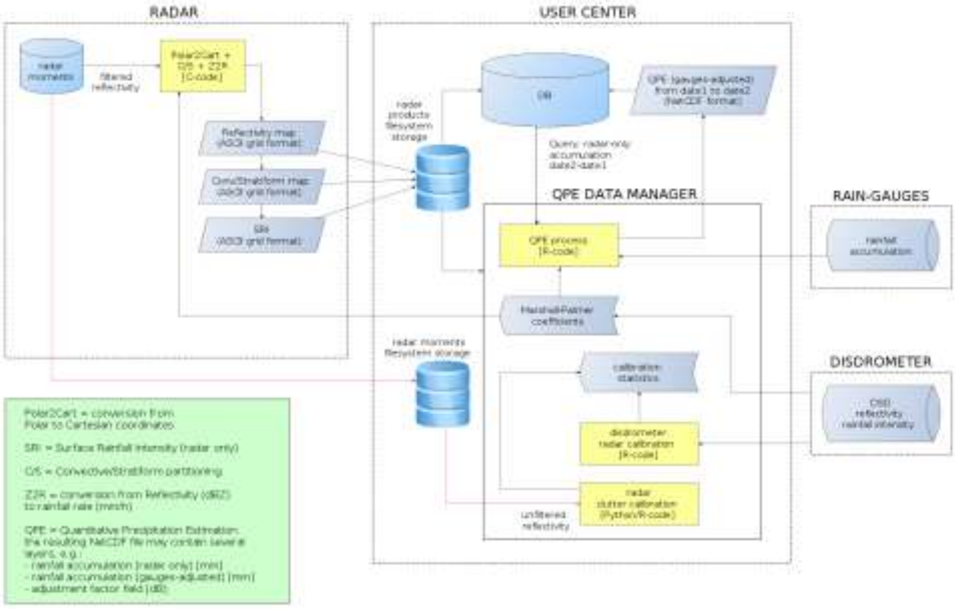


*Figure 5. The data flow and processes in the MARG Quantitative Precipitation Estimates.*

### 4.3. Data Management and User-specified Services

The MARG sensor will produce a vast amount of data concerning rates of precipitation, with the required spatial resolution (50 meters). The data management system will provide transparent transfer of the data from the microwave sensors to the user's equipment. The reflectivity (dBZ) to rain rate (R) algorithm will run on each sensor's computer, which will store, process, and transmit precipitation data to the user center. Taking into account a proposed range of 30 km, a spatial resolution of 100 m, and 8-bit amplitude resolution, the sensors will provide approximately 10 MB of reflectivity data per minute. This raw data will be processed by the dBZ to R algorithm, which is detailed above. The compressed data will then be transmitted *via* 3G or Ethernet. This data will be organized and stored on the user center's web server, using a database that is compliant with database standards such as gbXML. The database will contain the precipitation data, the measurement identification, and all available auxiliary meteorological data (e.g., temperature, and air pressure). Within this system, the precipitation data will be integrated into the geographical database, resulting in a real-time precipitation map of the target area. The MARG system will provide precipitation data to the users by means of a web server in the "user center module

### 5 . Results

The Project proposal has received funding from EC in the FP7 - 2007-2013 under grant agreement N° 315296. The project envisaged to built and set up two fully workable MARG prototype system for testing and validation in summer season of 2014. The main development task of the MARG project are the followings:

| | **Task** | **End-date** |
|---|---|---|
| WP 1 | System specifications | **31/03/ 2013** |
| WP 2 | Radar front-end development | **28/02/2014** |
| WP 3 | FMCW radar signal processing | **31/03/2014** |
| WP 4 | Antenna design, control and mechanics | **31/03/2014** |
| WP 5 | Development of the precipitation algorithms | **31/08/2014** |
| WP 6 | System integration and IT infrastructure development | **30/06/2014** |
| WP 7 | Testing and validation | **31/10/2014** |

The ongoing project has been reviewed by REA in October of 2013 and the final assessment report on it was compiled by Januay of 2014. The laboratory testing of MARG sensor will start in the spring season of 2014.

*MARG project start date*: November 1, 2012,
*MARG project duration*: 24 months
*Funding Scheme*: FP7 Research for the Benefit of SMEs
*Website*: www.marg-project.eu
*Consortium members*:
RTD partners: TU GRAZ, ARPA Piemonte, MFKK
SME partners: BHE, ON-AIR, MET-ENV, GEOGRAPHICA, PESSL, CNT

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