Calibration of a Six-Port-Based CW Radar Using Unknown Positions of a Target

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***Abstract*—In this paper a new approach to calibrate continuous-wave radars that utilize a six-port interferometer, is proposed. The presented procedure makes use of an arbitrary number of unknown target's positions and is suitable for nearfield application. With this calibration method also a target that changes its radar cross-section along the measured distance can be used. The procedure was tested utilizing a six-port-based continuous-wave radar operating at 2.35 GHz for various number of target's positions and their spread, showing the obtainable distance measurement error not exceeding 0.012 of the wavelength. Furthermore, the obtained measurement error distribution allows for defining simple and practical guidelines for calibrating radars with the use of the proposed method.**

Theoretical Background

A general diagram of a six-port-based CW radar is illustrated in Fig. 1. The key element is the passive power distribution network, which is fed by RF signal from a signal source connected to port #1. This signal is distributed to port #2, to which antenna is connected and to ports #3 – #6 equipped with power detectors $P_1 – P_3$ and P_{REF}. Next, the signal emitted by the antenna reflects from a target located at the distance D and is received by the antenna and distributed by the six-port network to power detectors $P_1 – P_3$. Taking the above signal propagation into account, the measured signal can be interpreted as the complex reflection coefficient Γ defined as:

$$\Gamma = \Gamma_0 + \Gamma_T e^{-2\gamma D} \tag{1}$$

where Γ_0 is the reflection coefficient of the utilized antenna in free space and Γ_T represents the reflection from target. Simultaneously, $\gamma = \alpha + j\beta$ is a complex propagation constant, which introduces exponential decrease of the magnitude and linear phase shift of the signal along with the distance D. Hence, the reflection coefficients measured subsequently for increasing distance D form a spiral on a complex plane, as shown in Fig. 2. The center of that spiral is located in Γ_0, which can be determined e.g., by taking the measurement when no target is in the antenna's field of view. After subtracting Γ_0 value, the distance D can be determined from the following expression:

$$D = \frac{\lambda}{4\pi}\arg[\Gamma - \Gamma_0] \tag{2}$$

where λ is the wavelength at the frequency of operation. It should be emphasized that for each CW radars utilizing a single frequency the range of unambiguously measured distance D is limited to λ/2. Moreover, in practice the usage of an uncalibrated radar makes the spiral more elliptic and shifted on the complex plane as seen in Fig. 3, leading to distinct distance measurement errors.

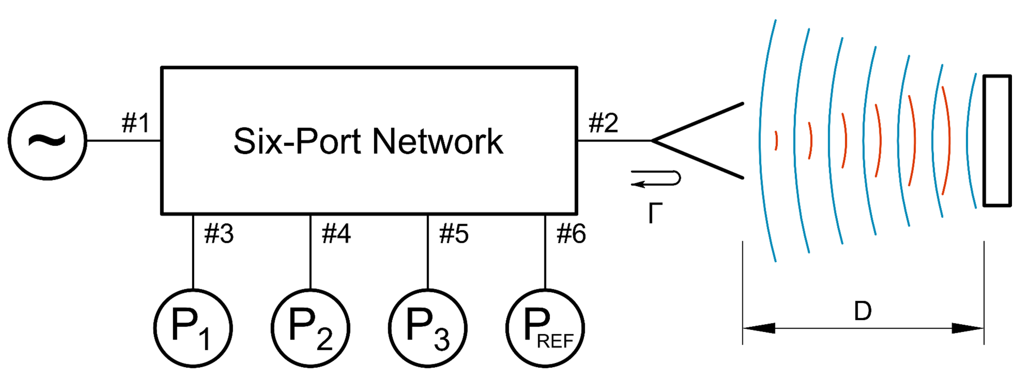

Fig. 1. A generic diagram of a six-port-based CW radar

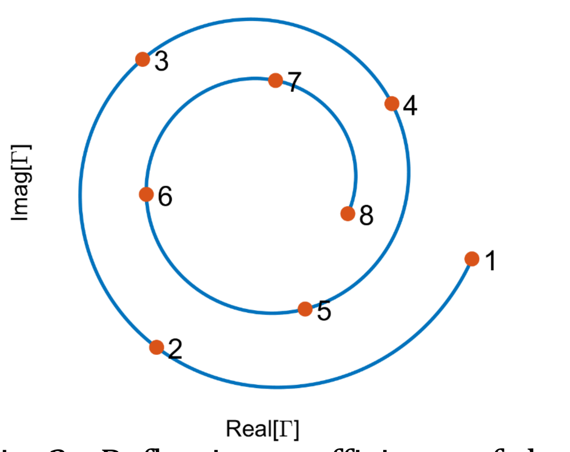

Fig. 2. Reflection coefficients of the antenna measured by an ideal six-port-based CW radar for eight target's positions equally distributed over the distance equal to wavelength

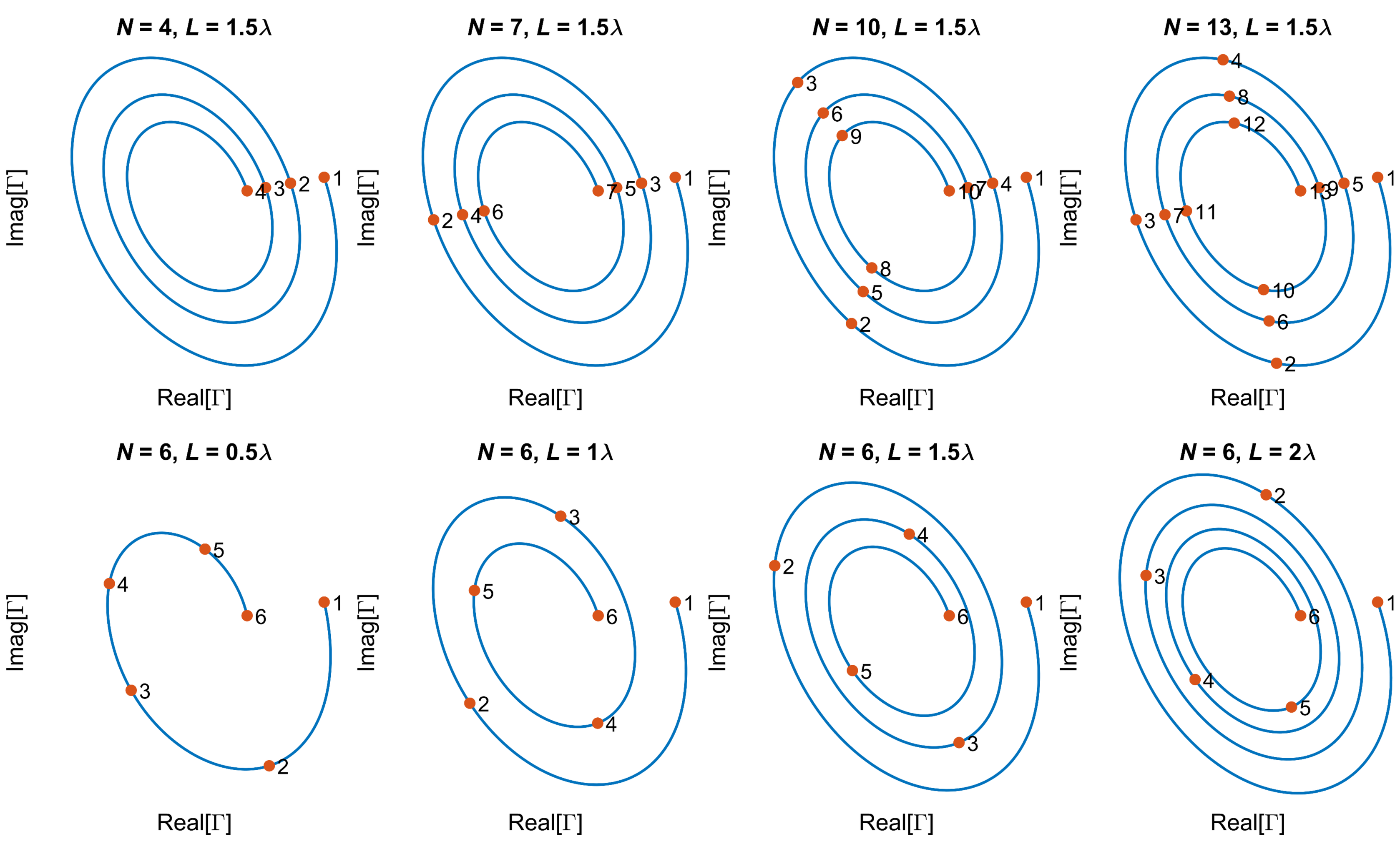

Fig. 3. Reflection coefficients of the antenna measured a real uncalibrated six-port-based CW radar for different number of target's positions N and different spread L defined as a distance between the first and the last position

Measurement Setup

For seeking optimum N and L values a six-port-based CW radar presented in Fig. 4 was used. It operates at the frequency of 2.35 GHz, utilizes the interferometer described in [1], and is fed with +15 dBm of power. The power measurement was realized using three integrated power detectors LTC5587 equipped with built-in 12-bit ADCs. To suppress their nonlinear responses three dedicated Look-Up Tables were applied. The utilized radar has separate antenna for transmitting and receiving, however, the relation between the received radar echo and the power values $P_1 – P_3$ can be described by [2] as well, hence the described algorithm can be applied with no modifications. The only difference for the radar having two antennas with respect to a radar with a single antenna is that the center of the spiral Γ_0 in (1) corresponds to the isolation between these two antennas, which in practice can be lower than the reflection coefficient of a single antenna. As the target a corner reflector having the outer edges' length of 100 mm was used. To set the target at an arbitrary distance from the radar a robotic arm was utilized. A photograph of the measurement setup is shown in Fig. 4.

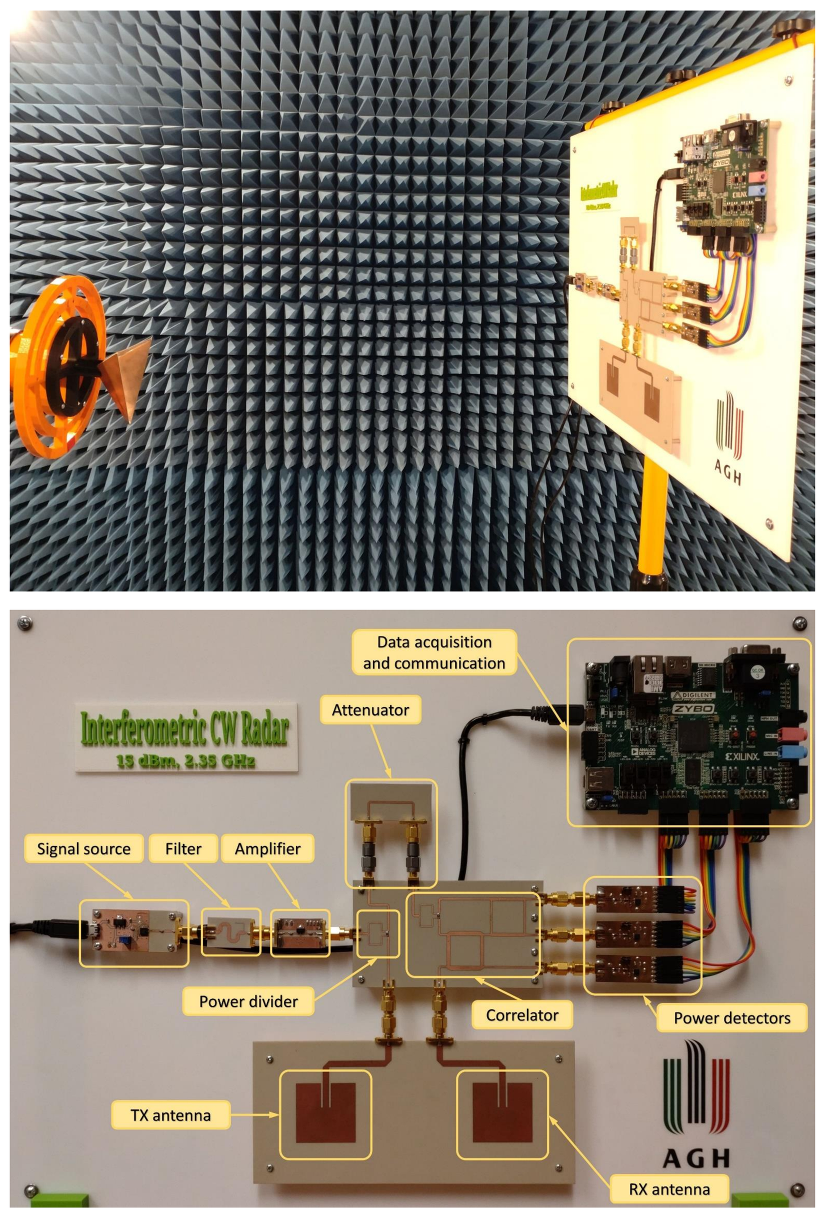

Fig. 4. The measurement setup in an anechoic chamber: (top) six-port-based CW radar and corner reflector on a robotic arm and (bottom) closer view of the radar

Radar's Calibration

To find the optimum N and L values the following procedure was performed. The target was placed in front if the radar's antennas at the distance D varying from 100 mm to 420 mm with the step of 0.1 mm. For each position the power readings $P_1 – P_3$ were acquired. Further, from the collected 3201 sets of power readings N sets of power readings corresponding to the target's positions with the spread L were selected and used as the input to the calibration algorithm. The procedure was executed for each N value from 3 to 20, and for the spread L values falling between 0 and 2.5λ (320 mm). Moreover, for each tested set of positions the first position was the one of 100 mm from the radar. Having this large number of calibration results, the collected power readings for 3201 target's positions were used to calculate the target's distance using (2), in which the system constants were taken from the corresponding calibration results. Finally, the calculated distance was compared against the genuine one and the maximum and RMS values of errors were calculated for each considered set of N and L values. The obtained measurement error distributions are illustrated in Fig. 5.

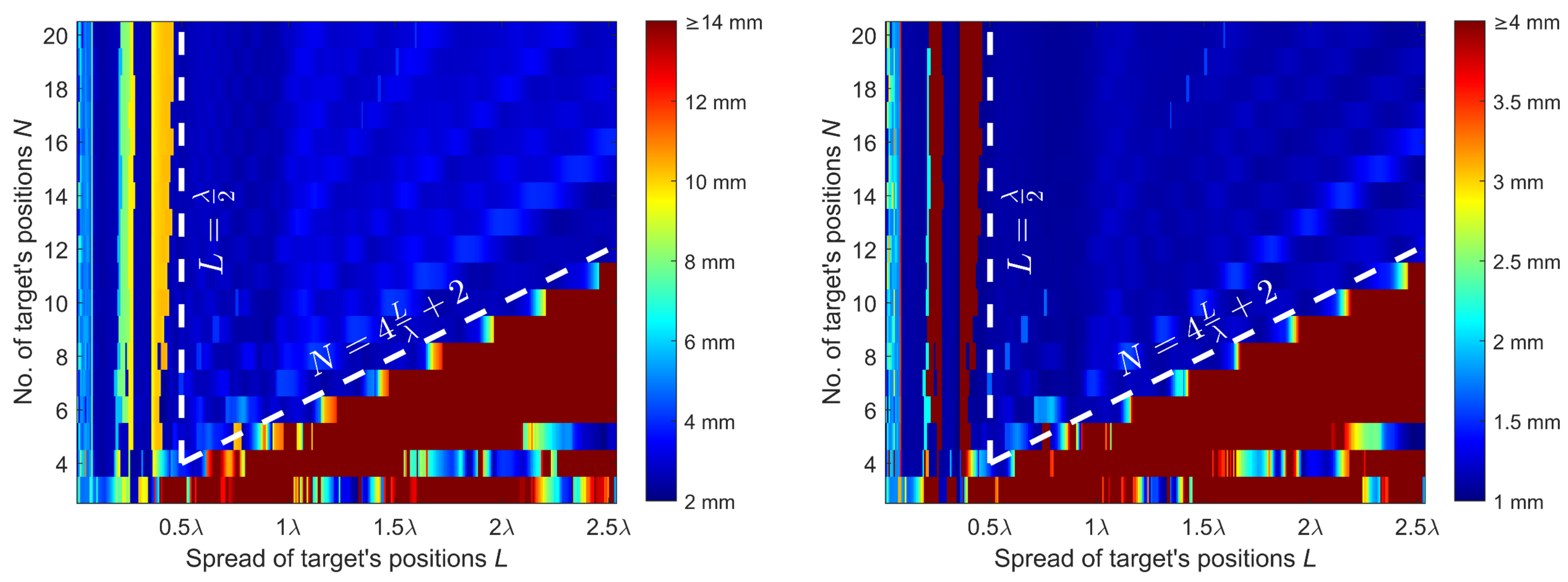

Fig. 5. The maximum (left) and RMS (right) distance measurement error obtained for different number of target's positions N and different spread L defined as a distance between the first and the last position. Measurements performed with the use of the six-port-based CW radar at the frequency of 2.35 GHz, for the distance range from 100 mm to 420 mm

References

[1] K. Staszek, "Six-port calibration utilizing matched load and unknown calibration loads," *IEEE Trans. Microw. Theory Techn.*, vol. 66, no. 10, pp. 4617-4626, Oct. 2018.

[2] K. Staszek, S. Gruszczynski, and K. Wincza, "Six-port reflectometer providing enhanced power distribution," *IEEE Trans. Microw. Theory Techn.*, vol. 64, no. 3, pp. 939-951, Mar. 2016.

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