Innovative low-cost antenna measurement method based on correlation technique

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1. Abstract

We have developed a novel method to determine antenna radiation patterns using pseudo-random bit sequences (PRBS). In contrast to conventional measurement techniques our method is insensitive to secondary path signals reflected by ground or walls, thus eliminating the need for large, expensive anechoic chambers or specially designed outdoor ranges. This can be of particular advantage for the characterization of antennas on cars, planes or buildings, or high-gain, low-frequency antennas. Measurement and simulation agree well.

2. Motivation

The conventional way of measuring antenna radiation patterns is to set up an echo-free environment and to perform a single-frequency (CW) power measurement. Depending on the antenna type this is usually accomplished using a specially designed outdoor range or an anechoic chamber (see, e.g., [4]). This is expensive and space-consuming, sometimes almost impossible, e.g., if antennas are mounted on cars, planes or houses.

By modulating the transmitted test signal and performing a correlation at the receiver the line of sight (LOS) signal can be measured (almost) without interference from reflected, hence delayed signals, as long as the bit duration is shorter than the relative delay of the shortest reflection path. Substantial echos may therefore be tolerated.

Using this method we have characterized manufactured monopole and horn antennas.

3. Measurement Setup

We employ a microwave and mm-wave channel sounder based on PRBS [1-3]. PRBS correlation technique is well known from radar technology [5]. The block diagram (Fig. 1) shows all major components, including clock and carrier recovery phase-locked loops (PLLs). The latter are not required for indoor antenna measurements. Details of the block diagram that are not essential for the matter of this paper are explained in [1-3]. The simplified block diagram (Fig. 3) illustrates the measurement principle. Additional elements, compared to a conventional (i.e. CW) antenna measurement setup, are a pattern generator, a delay line (with delay equal to that of the channel including down-conversion), and two mixers (gray). Correlation (multiplication) of the received, down-converted signal and the original, delayed signal is performed by a linear mixer. Due to the advantageous correlation properties of PRBSs the contribution of any secondary path with a relative delay of more than one bit duration T is reduced by a factor of $N = 2^n$-1 (periodicity of PRBS) compared to a simple power measurement. The shortest secondary path must therefore be at least $\Delta x = cT$ longer than the line of sight (LOS) path. The distance between the antennas should of course be sufficiently large to fulfill the farfield pattern assumption.

We used a pattern length of 2^{13}-1 and a data rate of $1/T$ = 800 Mb/s, which allows for a theoretical 78 dB suppression of all paths with > 1.25 ns relative delay (> 0.38 m detour). Our hardware suppressed unwanted signals only by ≥ 42 dB as can be seen from the measured impulse response (Fig. 2) of a reference channel. Postcursers are only ≥ 36 dB weaker than the main peak, but only precursers of the reference impule response limit the suppresion of delayed paths. Nonlinear distortion and/or reflections inside the channel sounder may be responsible for the unwanted preand postcursors. There is room left for a calibration procedure which should reduce the observed interference. The measurements were conducted in a lab (dimensions: 7 m length, 3.5 m height and width) full of tables, electronic equipment, metal shelves and two persons. Antennas were mounted 2.2 m high at 5 m distance. So the shortest secondary path, reflected by the ceiling, suffered a 63 cm detour. TX antenna was a 13 dBi horn, RX antenna was the device under test (DUT). The TX antenna was fixed, the DUT was slowly rotated by a step motor in 1.8° steps.

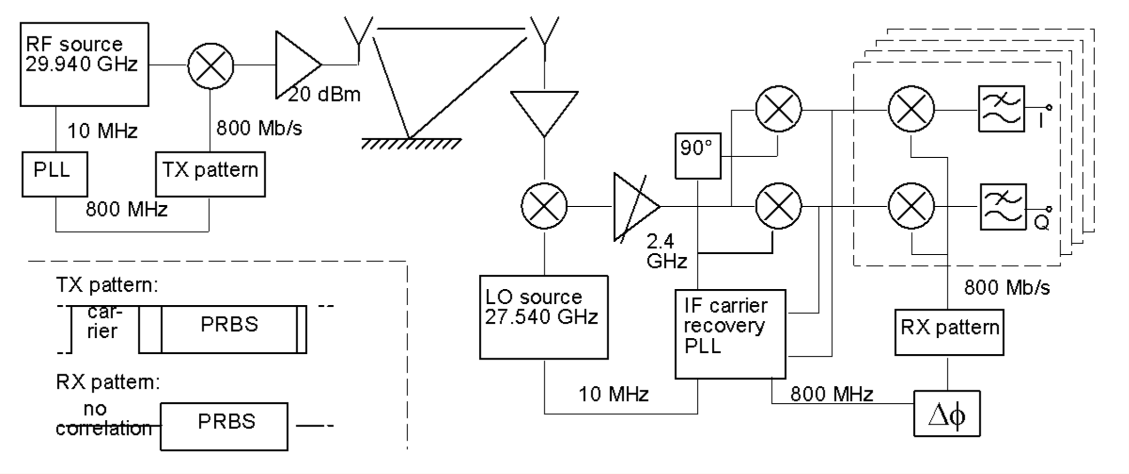

Fig. 1: Channel sounder block diagram

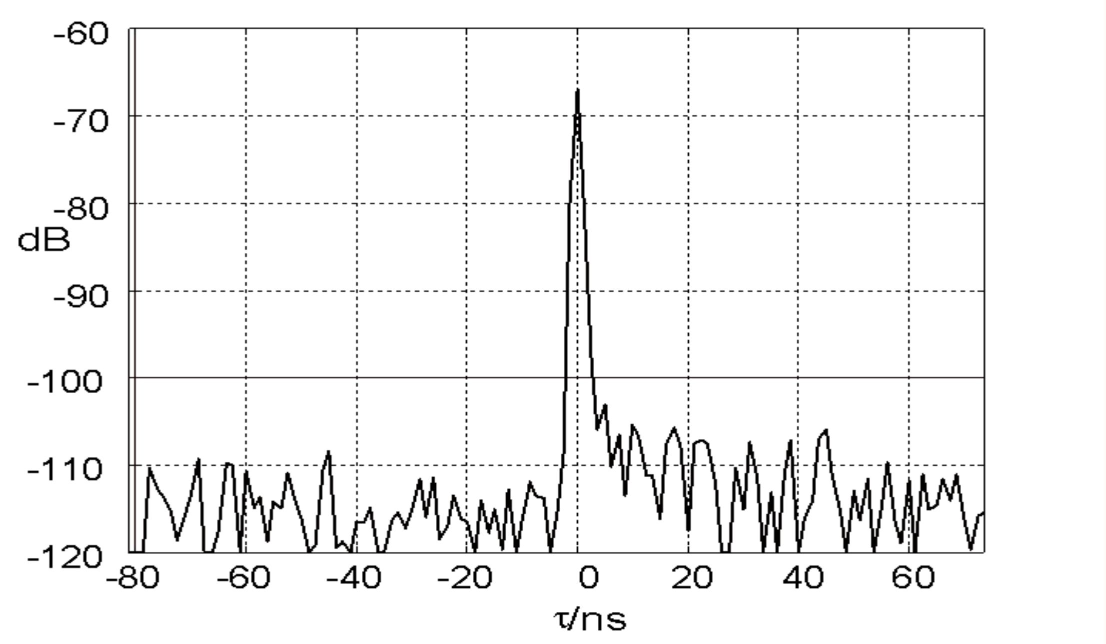

Fig. 2: Measured impulse response of a reference channel without multipath propagation.

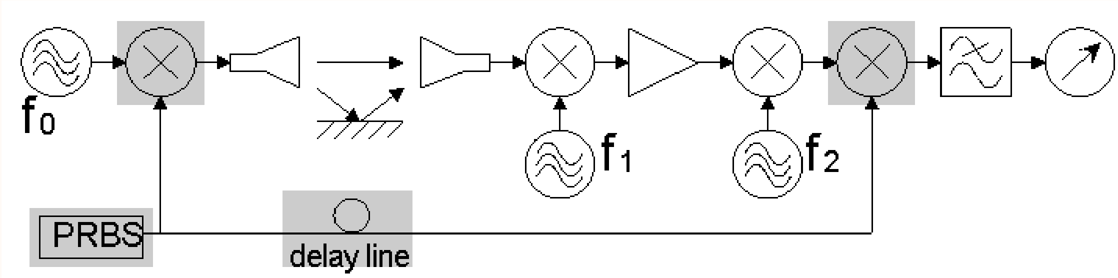

Fig. 3: Simplified block diagram explaining the measurement principle. Components not contained in a conventional antenna measurement setup are marked in gray.

Another PRBS generator and synchronization blocks (shown in Fig. 1) allow to separate transmitter and receiver completely. Indoors, a vector network analyzer operated in time-domain display mode may yield similar results, but at least outdoors over longer transmission distances our setup is easier, faster, and cheaper.

In contrast to the conventional single-frequency method, our setup performs a broadband measurement. On the one hand this limits the use of our method since it is not suited for measurement of very narrow band antennas. On the other hand it might be advantageous to measure the broadband radiation pattern if measurement data rate and application data rate are of the same order.

4. Measurement Results

Fig. 4 shows exemplary measurement results obtained with two 30 GHz horn antennas compared to a simulation using Huygens' principle. The two antennas have been used as TX or base station (BS) antenna (length $l = 150$ mm, aperture radius $r = 36$ mm) and RX or network termination (NT) antenna ($l = 20$ mm, $r = 5$ mm). The BS antenna was designed for a 3 dB half beam width of 30° to cover NTs within a large sector. The NT antenna was designed for 25 dBi gain to maximize signal to interference ratio, received power, and to minimize multipath propagation effects.

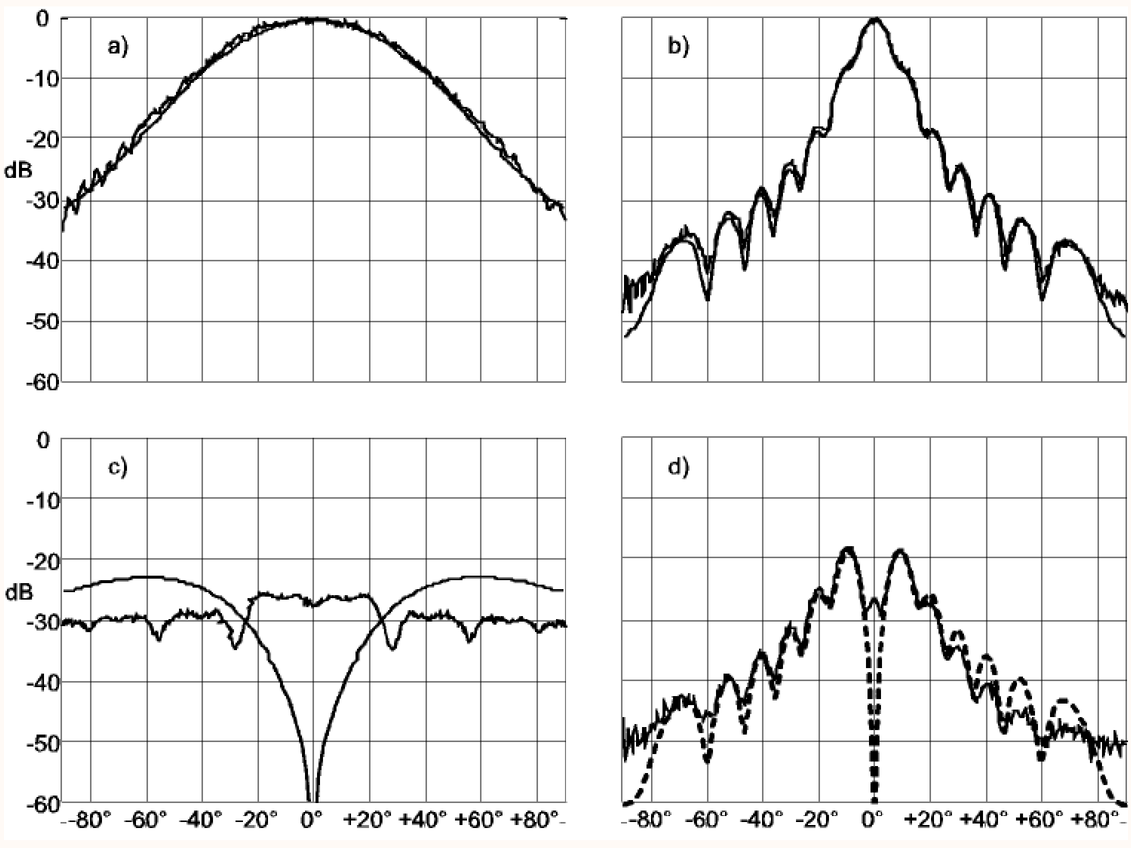

Fig. 4: Exemplary measurement result for two 30 GHz horn antennas with round apertures,

compared to simulation. Left: BS antenna, Right: NT antenna. Top: E-plane radiation pattern, Bottom: cross-polar pattern for diagonal polarization. Cross-polar measurements are normalized using the 0°-value of the corresponding co-polar measurements.

All co-polar measurements (also those not shown here) agreed well with simulation results (Fig. 4a) and b)). Observed discrepancies (< 2 dB and < 2° for the BS antenna and for first five side lobes of the NT antenna) may be due to simulation and manufacturing inaccuracies. Conformity between the measured cross-polar pattern of the NT antenna and simulation (Fig. 4d)) is also acceptable. Only the cross-polar measurement of the BS antenna (Fig. 4c) differs significantly from simulation. Although the measured radiation pattern is symmetrical and the measurement result is repeatable, there is no null at 0°. A possible explanation is that due to fabrication inaccuracies the employed square-to-circular waveguide transition transmits elliptically instead of linearly polarized waves, with a ratio of 27 dB between the main axes of the ellipse. The observed dynamic range of ~ 50 dB exceeds the minimum suppression of delayed paths (42 dB) significantly.

We have also characterized the radiation pattern of a simple omnidirectional λ /4 monopole antenna (Fig. 5). The antenna consists of an open coaxial stub and a metal ring. By adjusting the length of the center conductor and the position of the ring a return loss of -35 dB was achieved. Radiation patterns are slightly asymmetric due to mechanical asymmetries.

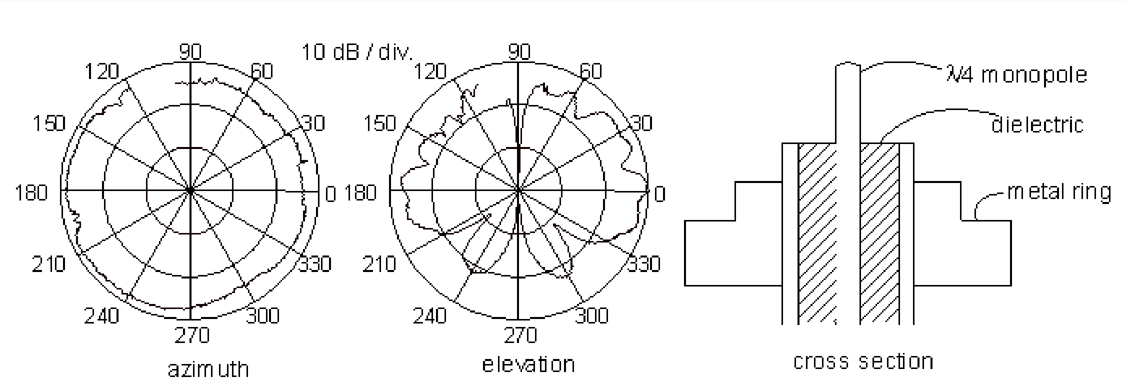

Fig. 5: Radiation pattern of a simple monopole antenna

5. Conclusions and Outlook

We have presented a correlation method which allows to determine antenna radiation patterns without anechoic chamber or specially designed outdoor antenna range. The method is particularly suited for antennas mounted on cars, planes or buildings, or for high-gain, low-frequency antennas, where the setup of an echo-free environment would be difficult or impossible. A PRBS channel sounder was employed to characterize 30 GHz antennas. Dynamic range was ~ 50 dB. Observed discrepancies between measurement and simulation were < 2 dB and < 2° (for the BS antenna and for the first five side lobes of the NT antenna).

6. Acknowledgment:

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7. **References**

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