Radio Channel Sounders for Modeling Mobile Communications at 28 GHz, 60 GHz and 83 GHz*

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***Abstract*—NIST has developed a new channel sounder design specifically to support radio-channel model development for 5G millimeter-wave mobile communications. Design elements include 40 GB/s real-time sampling; an electronically switched, high-gain, directional receive antenna array covering the upper hemisphere; and automated mobile operations. These features allow measurement of calibrated received signal strength and the spatio-temporal channel response for both indoor and outdoor environments under mobile conditions. An 83 GHz system is described in this paper while 28 GHz and 60 GHz systems, in process, have similar capabilities. To our knowledge, this work contributes the first channel sounder which is capable of broadband, 3D, mobile measurements at millimeter-wave frequencies.**

Keywords—5G wireless communications; channel sounder; millimeter-wave communication; propagation channel; radio channel; wireless system

I. Introduction

The use of alternative spectrum for wireless communications has been spurred by smart phones and other data-intensive mobile devices. The popularity of these devices has led to large increase of wireless data transmission and has resulted in a shortage of radio spectrum [1, 2]. The resulting "spectrum crunch" is a key driver for investigating the use of millimeter-wave frequencies for wireless telecommunications, as evidenced by the increased interest in 5G and related technologies [3, 4].

To satisfy scenarios envisioned for 5G networks, such as both stations moving at vehicular speeds in device-to-device communications [5], in this paper we describe an improved channel sounder for the 28 GHz, 60 GHz and 83 GHz bands. Our system design allows high-gain measurement of both the delay and angular properties of a non-stationary, millimeter-wave channel over the upper hemisphere.

In order to realize this, the three critical elements of our system design are:

1. Similar to a sliding correlator [6] but with recording three-to-four orders of magnitude faster, our system instead utilizes IF digitization of the received code, as in [7]. In this method, a PN code modulates an IF signal which is up-converted to the desired radio band and transmitted. The receiver then digitizes the IF signal and the correlation analysis is performed in post-processing. This reduces the measurement period to the transmitted code period only, which, for the case illustrated here, is 2047 ns.
2. A receiver formed by a two-dimensional array of 16 directional, high-gain, scalar-feed-horn antennas. The combined field of view of the array covers the upper portion of a hemisphere, enabling angular diversity in both azimuth and elevation. Electronic switching between the received IF signals at each element occurs within 65.5 μs, resulting in a maximum coherence time corresponding to independent transmitter and receiver vehicular speeds up to 99 km/h each[1]. Most directional channel sounders utilize manual or mechanical rotation [5(Sect. B.4), 6, 8-10], which is relatively slow.
3. Our system features an untethered transmitter-receiver pair, GPS-equipped for outdoor operation and robotically navigated for indoor applications. The form factors are compact, which allows a roof- or robot-mounted antenna. The system is fully automated, enabling extensive data collection within the battery life of the unit, the latter exceeding three hours on a single charge.

In Section II, we describe the channel sounder and its specifications, and in Section III, we show measurement data collected in an indoor reflective environment at 83 GHz, followed by a summary.

II. Description of Channel Sounder

The block diagram appears in Fig. 1. The 28 GHz and 60 GHz sounders (in development) have identical characteristics except for the RF and IF frequencies, and transmitter power levels (due to availability of off-the-shelf power amplifiers at the various frequency bands). The systems share common hardware sections such as the arbitrary waveform generator, digitizer, timing circuitry and positioning systems.

[1] At these speeds, applications may include exchange of information at Gb/s data rates during the short period in which vehicles are in range of each other.

A. 83 GHz Transmitter

The transmitter uses an arbitrary waveform generator (AWG) to create the modulated intermediate-frequency (IF) waveform, where the modulation consists of a maximal-length PN code. The IF signal is then amplified and up-converted to a center frequency of 83 GHz. The IF and RF signals are band limited to the null-to-null bandwidth of the code spectrum which, in this case, is 2 GHz.

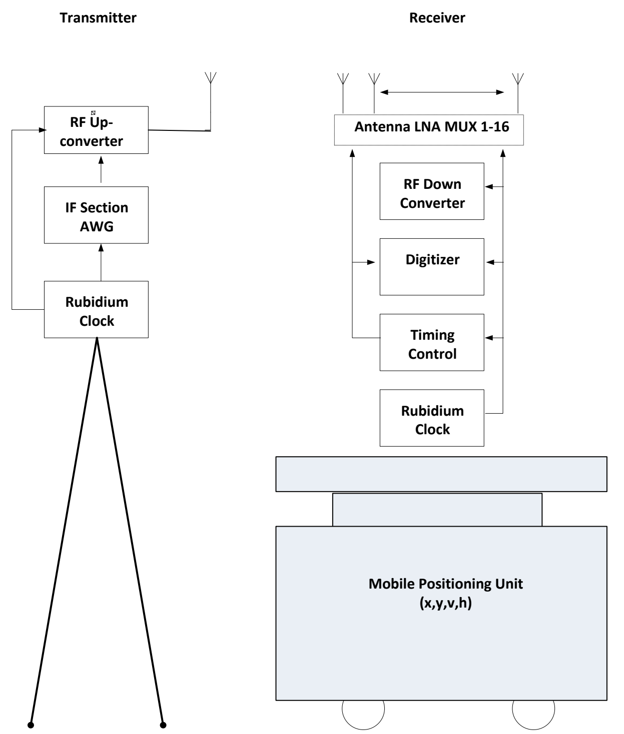


Figure 1: Block diagram of the NIST millimeter-wave-frequency channel sounder showing the transmitter and receiver sections. The receiver is mounted on a mobile positioning unit which provides position, velocity and heading (x,y,v,h) of the receiver.

B. 83 GHz Receiver

The front end of the receiver is a custom-designed octagonal waveguide antenna multiplexer shown in Fig. 2. Sixteen 45°-beamwidth scalar-feed-horn antennas feed 16 low-noise amplifiers (LNAs). Electronic switching is used to select the output of each amplifier sequentially with a switching speed of 35 ns. The received signal is down-converted from 83 GHz to a 5 GHz IF for digitization.

The coordination between the multiplexer and the digitizer is controlled by a precision timing section. It includes a rubidium clock for phase locking the local oscillator (LO) of the receiver, the multiplexer control signals, the digitizer clock and external triggers. A similar rubidium oscillator at the transmitter allows for untethered operation while maintaining frequency and timing stability between the transmitter and receiver.

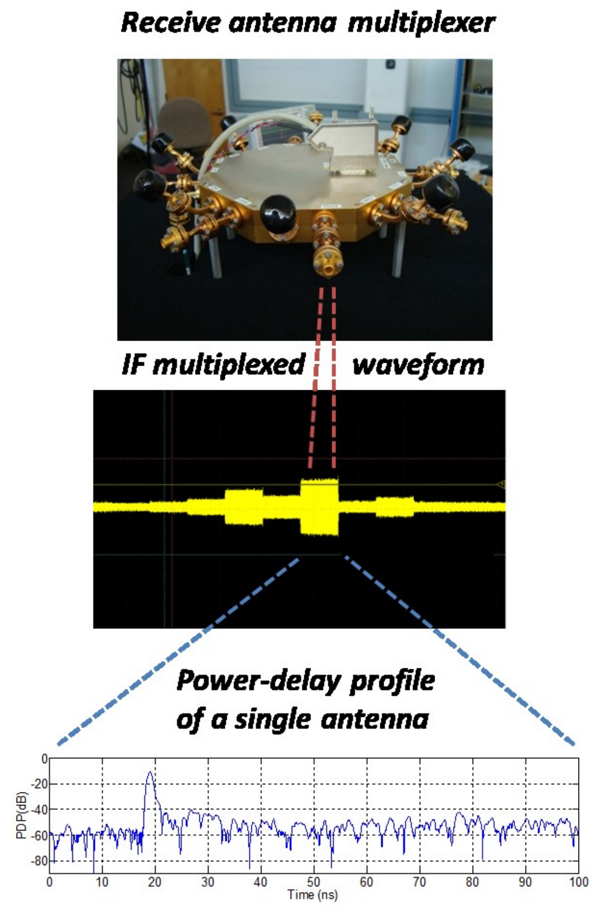


Figure 2: An RF signal from a single receive antenna element (top photo) is digitized after downconversion to IF (middle plot). The digitizer record contains the IF signals from all 16 antenna elements. Received code words are then extracted from the IF record and processed at baseband to yield the power delay profile for each antenna element and angle-of-arrival (bottom plot).

Figure 2 shows the signal flow from the receive antenna thru the digitized IF to an extracted power delay profile (PDP). This PDP was derived from the data from one antenna channel (*i.e.*, one angle-of-arrival). Data from multiple rotations of the antenna array were used to calculate averaged power delay profiles. The averaged PDPs can be processed further to yield channel metrics versus angle-of-arrival. The light-colored IF signal in the middle section of Fig. 2 shows the switching of the antenna array, as well as the relative levels of IF signals recorded at different angles-of-arrival.

C. Mobile Positioning System

The channel sounder was designed for indoor and outdoor mobile radio measurements. To analyze the data, the position, velocity and heading of the antenna array are needed. For outdoor use, a GPS positioning system will be utilized. For indoor use, a robotic mobile positioning system, shown in Fig. 1, is used to move the antenna array.

The mobile positioning system uses a laser ranger finder to measure its position, velocity and heading. These data are queried and stored with the digitizer data at millisecond intervals. The survey area is first mapped using the robot. Once the map is created, the onboard computer can direct the robot to positions on the map while recording position information from the navigation system, as well as directing the digitizer data collection. In this way, position data as well as angle-of-arrival information, can be collected while the robot is moving.

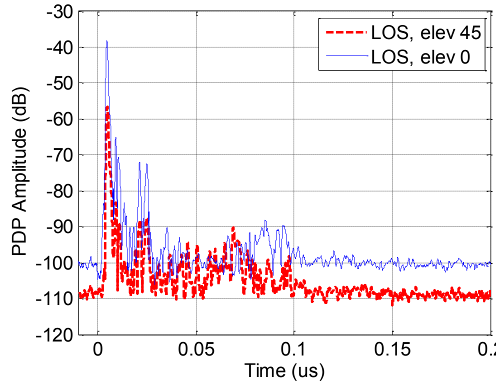
III. Initial Measurement Results

The system has been tested indoors in a 7 m by 7 m area. The floor of this area is a metal ground plane. The walls of the room are cinder block, and two of the walls directly bound the metal platform. The room ceiling is approximately 10 m high. Figure 3 shows averaged power delay profiles calculated from data from eight rotations of the MUX under static conditions. The transmit antenna was a standard gain horn and the receiver assembly was stationary at a distance of 3 m.

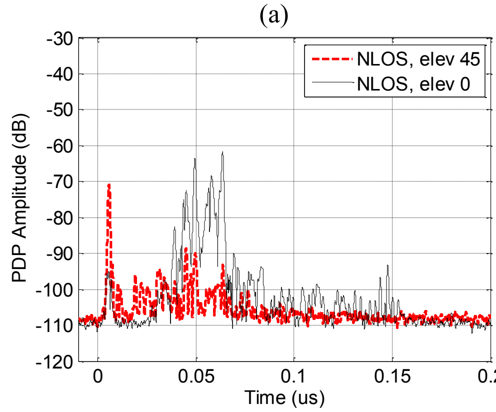
The receive antennas in Fig. 3(a) were pointing directly at the transmitter for 0° and 45° elevations. We see a strong first arrival at 10 ns and similar reflected signals for both elevations. Fig. 3(b) shows the same elevation angles for receive antennas pointing directly away from the transmit antenna. Here, we see signals dominated by multipath with stronger reflections in the azimuthal plane. These results indicate that elevation information may be important for modeling multipath in some indoor environments. The data in Fig. 3 also illustrate that all significant multipath components have died out before approximately 0.15 μs for this reflective environment. Analysis of mobile measurements will yield both channel coherence time and Doppler.

IV. Summary and Conclusion

We described a new millimeter-wave channel sounder operating at 83 GHz and presented initial measurement results. The channel sounder features fast, direct digitization and an electronically switched antenna array to record channel impulse responses for angles-of-arrival covering approximately the upper hemisphere. Other channel sounders operating at 28 GHz and 60 GHz are underway. The data acquired by these sounders will be used to derive channel characteristics and support channel model development for future wireless systems.



(a)



(b)

Figure 3: Power delay profiles measured by receive antennas pointed directly toward (LOS) or away from (NLOS) the transmit antenna for elevation angles of 0° or 45° with respect to the transmit antenna. The lower noise floor in (a) represents the measurement system noise floor (dominant for weak signals), while the upper noise floor represents the correlation noise floor, theoretically 66 dB.

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