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Mmw channel sounder for dynamic SIMO measurements

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Sondage de canal – bande millimétrique / Channel sounder - millimeterwave

1 Abstract

This paper presents a mmW SIMO channel sounder currently under development at IMT Atlantique / Lab-STICC. Today, to our knowledge, there is mmW sounder for dynamic SIMO measurements. The objectives of the paper are threefold. First, to propose a state of art and an analysis of the measurement capacity related to channel sounder in the millimetric bands. Second, to describe the architecture of the system based on USRP boards and on a commercial board for the millimeter wave part. Third, a multibeam mmW front-end is presented.

2 Introduction

To meet growing demand for higher throughputs, advanced digital communication techniques based on multicarrier modulations, multiple antenna systems (MIMO), are under study. A way to increase throughputs is to deploy cellular systems operating in mmW bands. These high frequency bands offer very large bandwidths (some of them are unlicensed) that are one of the simplest ways to increase system capacity, and lead to enhanced miniaturisation of radio-frequency architectures. In such a context, massive MIMO (M-MIMO) systems, with up to hundreds of radiating elements at the access point (AP), are extremely attractive solutions to achieve very high data rates for multiple users sharing the same spectrum at the same time, with low power consumption thanks to the use of specific analogue/digital precoding techniques. Characterisation and modelling of radio channel in the mmW frequency bands are needed for the development and analysis of communication systems in this band. Since several years, this domain is very active in the context of 5G NR deployment. Moreover, any effective hardware implementation of such systems must rely on a realistic knowledge of radio channel impairments and mmW propagation / antenna characteristics, especially for outdoor and railway communications for which the results available in the most recent literature are very limited.

3 mmW channel sounding state of art

This part presents a state of art of the different type of mmW channel sounder available today and analyse their capacity for a channel sounding in dynamic scenario. A first category is based on the use

of a VNA (Vector Network Analyser) with external up and down converter. For example, Helsinki university developed a 60 GHz MIMO Channel sounder with a synthetic 3D array antenna [1]. The antenna is a biconical antenna with an omnidirectional radiation pattern. A mechanical spatial scan of the antenna allows to determine the DOA (Direction Of Arrival). The TX and the RX must be connected with cable to the VNA. This equipment is used for indoor and static scenario because the duration of a measurement is around 20mn.

To avoid the frequency sweep of an VNA, the generation of a pulse signal allows directly to measure the complex CIR (Channel Impulse Response). Shorter is the pulse duration, better is the time resolution. *Talbi et al.* developed a pulse-based channel sounder at 60 GHz presented in Figure 1[2]. To allow medium distance measurement, the synchronisation between the TX and RX is ensured by an optical link modulated with RF signal. Very high gain antennas up to 46 dBi are used to improve the spatial resolution and the range. This channel sounder allows CIR measurement in SISO dynamic environment.

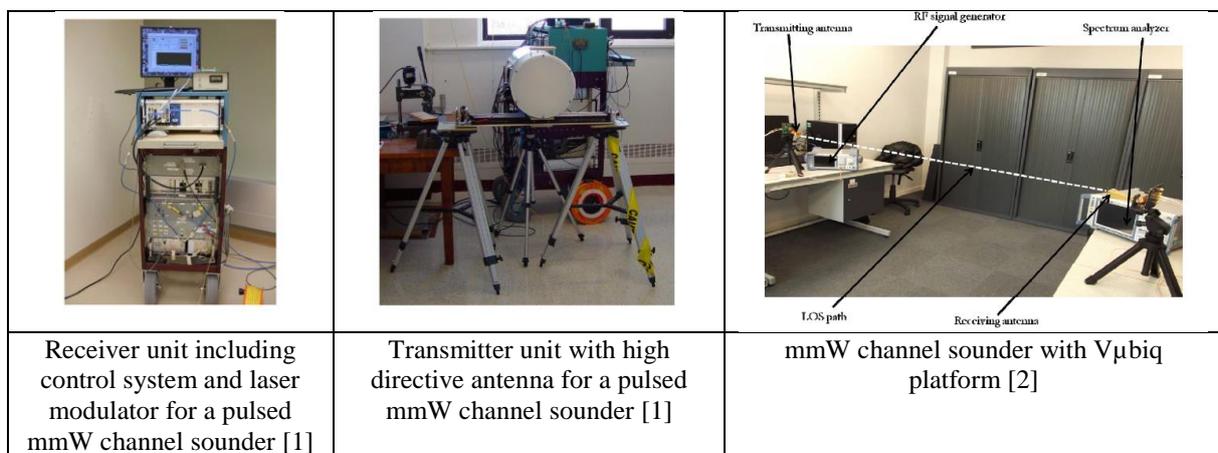


Figure 1. mmW channel sounder

A channel sounder, based on the VUBIQ platform, is designed by *Karadimas et al* to perform time domain propagation measurement at 60 GHz [3]. The system is simple with a RF generator and a spectrum analyser connected to the VUBIQ platform (**Erreur ! Source du renvoi introuvable.**). Only power measurement is done. This equipment allows only to analyse the impact of a link blockage but does not allow a CIR measurement. It can be used for SISO dynamic scenario.

Another mmW channel sounder is based on the “Rusk” channel sounder developed by TU Ilmenau. [4] It has been extended to mmW band with front-end to up and down-convert intermediate signals. This combination is enabling us to perform accurate dynamic propagation measurements. The mmW front end extender are realized with classic waveguide component and with standard horn antenna. This equipment allows to perform CIR measurements in SISO dynamic scenario.

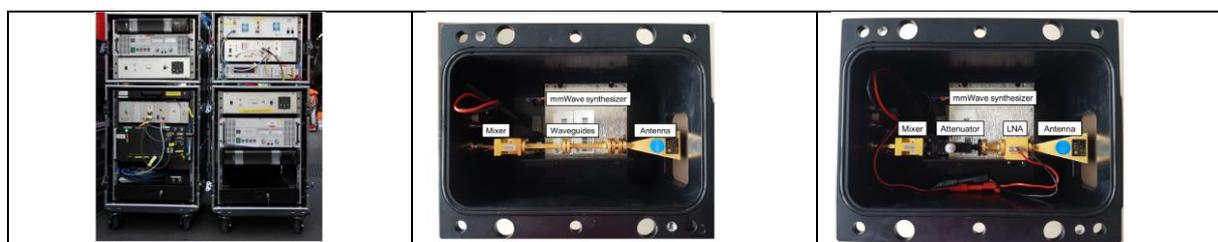


Figure 2. RUSK-DLR channel sounder transmitter and receiver racks.

In dynamic scenario, the goal of our work is to analyse the propagation in railway environment, in the context of T2T (Train to Train) or T2I (Train to Infrastructure). The use of mmW frequency can support

high data rate and low latency services. In [5] [6], multipath effect is well identified in these environments but there are no results concerning the DOA (Direction Of Arrival) of paths. In [7], *Yang et al* present DOA results but in static environment.

Today, to our knowledge, there is quasi no low-cost channel sounders based on a beamforming technique for MIMO channel modelling in the mmW band in dynamic environment. Currently, in the context of the ANR mmW4Rail project, the research laboratory IMT Atlantique / Lab-STICC designed a portable channel sounder based on SDR (Software defined Radio) devices (Figure 3) [8].

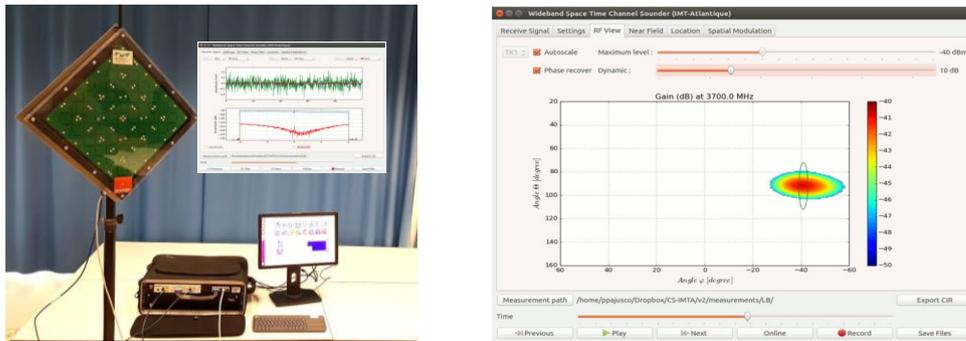


Figure 3. IMT Atlantique channel sounder up to 6 GHz.

From this first version, our final goal is to design an extended mmW front-end allowing channel sounding in quasi-real time of the CIR and the DOA at 60 GHz for dynamic environment. The following parts present respectively the global architecture of the channel sounder and the multibeam 60 GHz front-end for DOA measurement.

4 mmW channel sounder architecture.

1- Hardware Setup

The system is composed by a commercial product of millimeter-wave, which integrate a receiver and transmitter module. The Analog Device EK1HMC6350 is a demonstration board, which include HMC6300 and HMC6301, respectively the transmitter module and the receiver module.

The transmitter is composed of the HMC6300 can operate from 57 to 64 GHz, with up to 1.8 GHz bandwidth. The board supports different modulation provided by a differential baseband I/Q input. A heterodyne IF architecture in addition of an RF mixer is used inside. The **Erreur ! Source du renvoi introuvable.** shows the architecture.

The R&S SMJ 100A is currently used to generate the 71.42857 MHz reference clock to control channel bandwidth (250 MHz). Moreover, the equipment is also used to provide I/Q signal with a bandwidth of 80 MHz in single-ended in order to emit a flat spectrum signal. To increase the RF output power, we consider an amplifier with a gain of 25 dB and a P1dBm of 25 dBm. The antenna could be classic horn antenna with 15 dBi gain.

The receiver part is composed of, currently, a horn antenna with the same specifications as the transmitter antenna. The HMC6301 has a variable gain from 0 to 69 dB. The HMC6301 down-converts the 60 GHz signal to analog I/Q differential baseband signal.

A USRP X310 is used to convert the analog signal to digital. The maximum bandwidth is 160 MHz, and all the equipment are synchronized with a 10 MHz signal reference from rubidium.

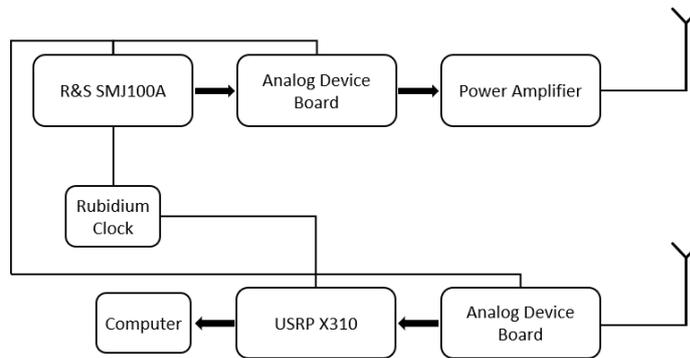


Figure 4. Transmitter and Receiver Part

2- Software Setup

An addition of the hardware setup, a software has been developed on PyQt from python to control the USRP, the receiver and transmitter card. The software proposed by Analog Device is only present on windows system and cannot control specific element. The Figure 5 shows the control window used to control the different gain on the card.

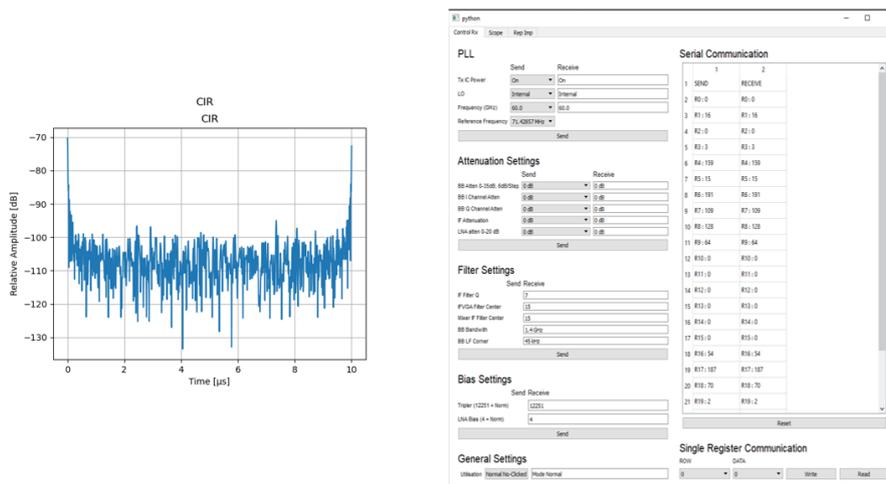


Figure 5. Window Control Receiver (right) part and example of CIR measurement.

Another window is used to perform measurements. At the end of the measurement the CIR is shown for the different angle measured.

3- Specification

This system employs the Wiener inversion to calculate the CIR of the channel. A back-to-back calibration file is recorded with a direct connection between. For 160 MHz, the time resolution is equal to 6.25 ns. The maximal duration of the sounding process at a given position corresponds to 1000 points of measurements, so a maximal duration of 10 µs.

| | | |
|--------------------|--------------------|--------------|
| Carrier Frequency | | 57 to 64 GHz |
| USRP Specification | Sampling rates | 200 MHz |
| | Max Bandwidth | 160 MHz |
| R&S SMJ100 A | Sampling Frequency | 100 MHz |
| | Max Bandwidth | 80 MHz |
| Time resolution | | 6.25 ns |

| | |
|---------------------------|------------|
| Maximum Time Measurements | 10 μ s |
|---------------------------|------------|

Figure 6. Currently specifications of the channel sounder.

5 Multibeam 60GHz front-end.

Due to the high free space losses at 60 GHz, directive antenna has to be used to obtain a good sensitivity and allowing DOA measurement. In dynamic scenario, a single beam with a mechanical scan is not adapted. A solution based on a fast-electronical switch of different beams is proposed to scan the environment. This approach is acceptable if the switching time is small in comparison to the environment modification, for example a maximum vehicle speed. Due to technological constraint, a linear antenna array is investigated.

Depending on the type of environment and the distance (short or medium), two architectures are proposed. For short distance, a full digital beamforming allows to have a complete freedom about the DOA. But due to the low gain of the antenna, the sensitivity will limit the measurement range. Figure 7 presents the architecture of the mmW front-end with 8 antennas. The main challenge is to minimize the interconnection losses at 60 GHz between the antenna and the 60 GHz downconverter with a high constraint of integration imposed by the half wavelength distance between antennas. Furthermore, the LO (Local Oscillator) of each mixer must be synchronised.

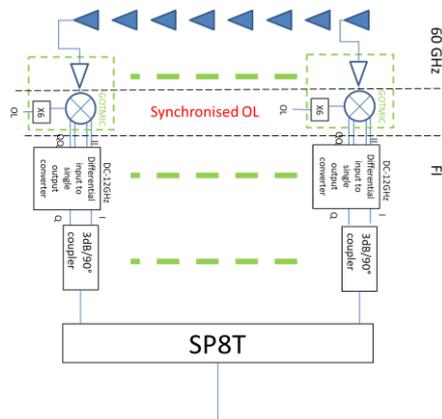


Figure 7. Full digital beamforming RF front-end architecture.

For medium distance, high gain antenna is necessary to improve the sensitivity. We propose to add a transmit array antenna just in front of the array antenna to design a hybrid analogic and digital beamforming. This allows to generate 8 beams every 10° and each with a beamwidth of 10° . The architecture and the principle of beamforming are presented on the Figure 8.

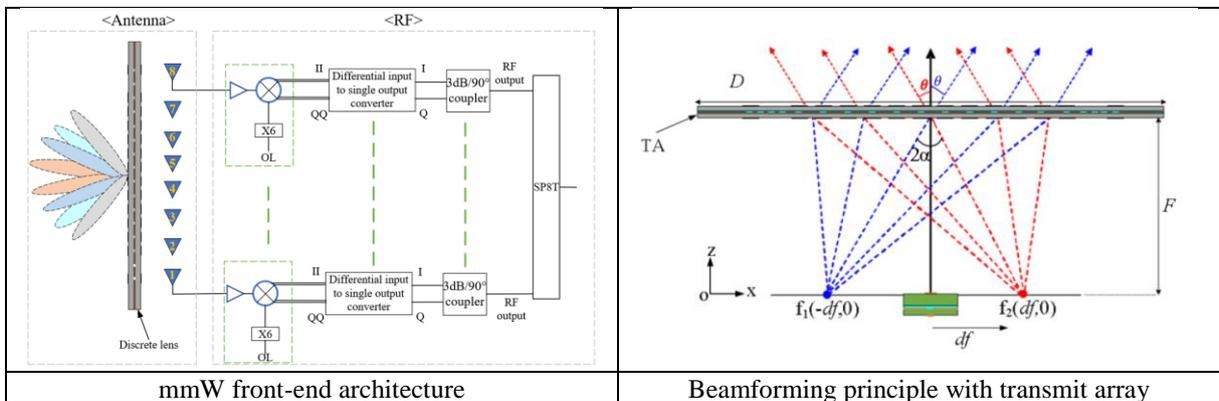


Figure 8. Hybrid analogic and digital RF front-end architecture.

The down converter is a MMIC chip including also an LNA (Low Noise Amplifier) produced by GOTMIC. The Figure 9 presents the PCB circuit. The top face is dedicated to the connection of the MMIC chip by bonding wire. The bottom face is dedicated to the generation of the different DC voltage.

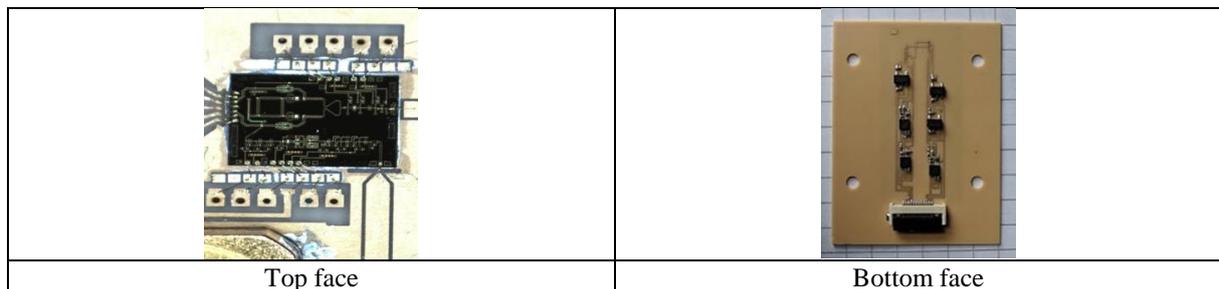


Figure 9. Front-end RF PCB.

The 8 antennas are small 2X2 patch array antenna to obtain a minimum gain of 8dBi and to have an optimum illumination of the transmit array in order to avoid spill over effect.

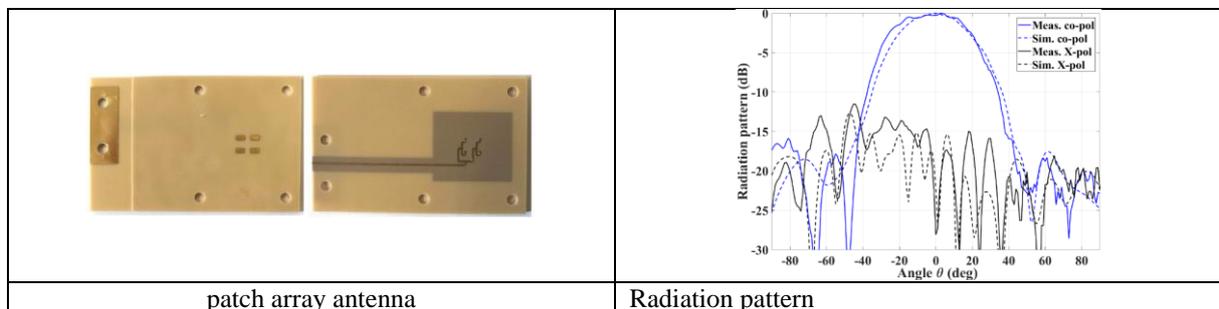


Figure 10. 2x2 patch array antenna.

The transmit array antenna is a multilayer PCB (Figure 9) [9]. Each cell is composed of two patch and a coupling slot allowing the control of the phase shift wanted.

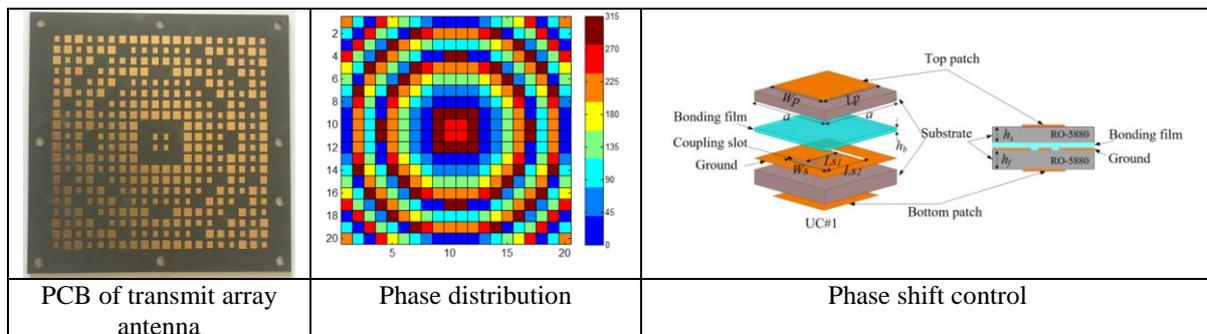


Figure 11. 60 GHz Transmit array

The following figures present the radiation pattern simulated and measured respectively in the E plane (a) and in the H plane (b).

By moving the primary source, a beam scanning is done. Two types of transmit array have been studied and tested: one unifocal and the second bifocal. The Figure 16 presents the multibeam radiation pattern and the scan losses. We can observe the interest of the bifocal type for high scan angle.

The figure presents the integrated mmW multibeam front-end including the LO distribution to ensure the synchronisation between the 8 ways. In order to scan in both plane: azimuthal and elevation, the complete channel sounder will be installed on a rotating motor.

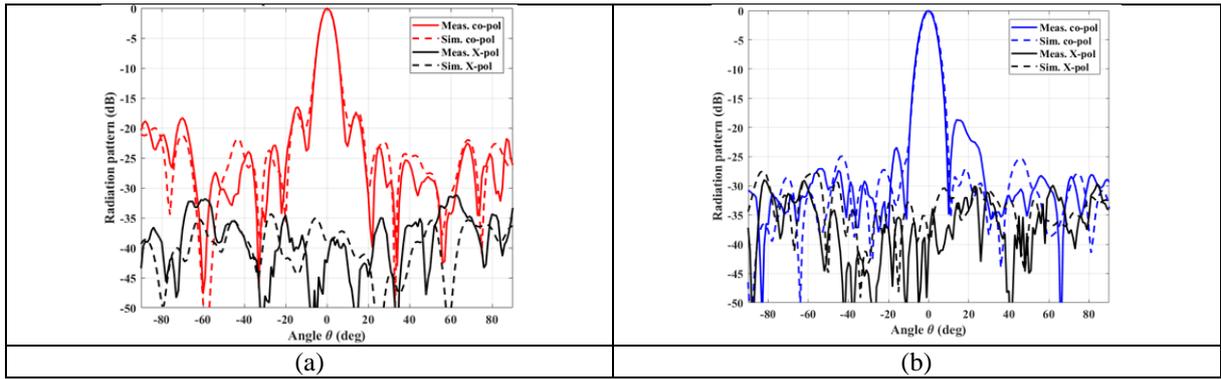


Figure 12. Bore-sight radiation pattern of the transmit array.

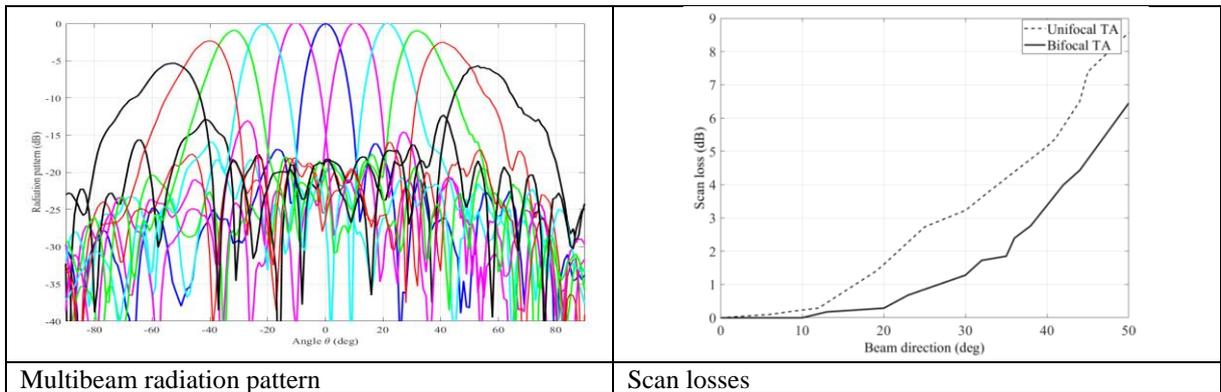


Figure 13. Multibeam radiation pattern and scan losses.

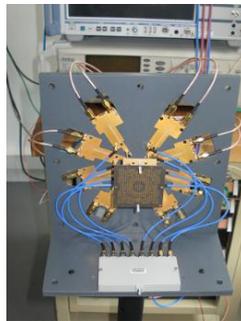


Figure 14. Multibeam 60 GHz front-end.

6 Conclusion

This paper presented a SIMO channel sounder currently in development at IMT Atlantique/Lan-STICC with the use of commercial board and USRP. Moreover, a lens antenna with 8 transmitters array has been presented with this divider in order to have an only output. Currently in test at the laboratory. The first outdoor and dynamic measurements will be conducted soon in order to start the first measurements in railway environments.

Acknowledge

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