Low-Cost Small B5G Antenna of a Metamaterial Toughening the LoS Signal in Indoor Propagation

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Abstract—**In this paper, a high-frequency band wireless link is built and checked from the view-point of indoor propagation. As is done in 5G millimeter-wave communication, a high-directivity antenna developed to compensate for path loss and negative effects in the multi-reflection environment is looked into as the device under test. The high directivity realized by a metamaterial lens flat and small different from a long horn or a large-aperture array can strengthen the received signal on LoS. In the experiment with a corridor sized 2.3x4.0x2.7m^3 and 10 GHz, the magnitude of the received power becomes -34 dBm much greater than -83 dBm of the FCC path-loss model**

Keywords—Antenna, Path loss, Mobile link, Received power

I. INTRODUCTION

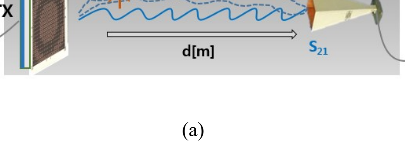
Before a mobile infra structure is laid out, the environment for mobile networking needs to be characterized and understood from the electromagnetic and communication perspectives. As to a transmitter (TX) which is fixed like the base-station and relays, mobile terminals as the receiver (RX) freely go around and the metrics such as the received power, BER and CDF are generated as the relationships of the TX vs. RX positions. This is what we call propagation model or channel model [1]. In this analysis, path loss read from the received power is treated as something important now that it brings the mobile carrier an idea to decide antenna gain and positions to put the access point (AP) antennas. This is required whether mobile networking or broadcasting services or low-frequency or high-frequency.

Jawhly et al tried to find the mathematical model which shows a similar trend of the FCC empirical model for VHF and UHF bands[2]. By adjusting the coefficients of two terms having the distance, the curves of the two models overlap at most of the sample points. Robles-Enciso et al tested the path loss formula for various mobile protocols, say, LoRa, Zigbee and 5G [3]. They conducted experiments and dealt with path loss for two NLOS cases in a building. The field strength was detected and given to the fictitious grid over a Spanish town [4]. It was painted in color to indicate the hot spots and cold ones for GSM and UMTS and FM broad-casting. Changed to high frequency bands exemplified with 28 GHz and 38 GHz, the signal transmitted from one relay antenna is propagated in the lay-out of a city and the field strength was calculated by the ray-tracing [5]. The curve is compared with that of the empirical model. Zakeri et al used a full-wave EM tool to plot the field strength of an mm-wave signal for an office building [6]. As for a horn antenna as the TX located at a corner, the received power at the monopole antenna on the NLOS was calculated and put together with the FCC path-loss model. Samad et al adopted the commercial double ridge horn to the TX and RX between which there is a stairwell[7]. The path loss for 28 GHz is measured as 81 dB for the input power of 20 dB at the TX. This is replicated to an emergency exit[8]. Correction terms and coefficients are trimmed to make the average of the measured mm-wave path-loss matched with the formula. The site is changed to a room with a cabinet, a rack and partitions electromagnetically exposed to the base-station of Yagi-Uda arrays on 12-sectors and responded by the monopole antenna working at 28 GHz[9]. Selecting the polarization alternately of the sector arrays can make room for levels of similar field strength, and verifies that the co-pol received power is superior to other combinations. Inomata et al shone the signal of 150 GHz to the surfaces of a model building after confirming the link between the TX and RX horns at an anechoic chamber[10]. It revealed that the surface roughness of the wall causes scattering and degrades the field strength.

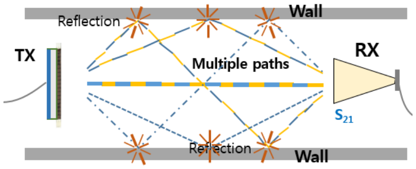
In this paper, a method is proposed to toughen the signal of the high frequency-band antenna as a small form-factor against functional degradation due to the multiple reflections in a narrow space like a hall-way. High directivity is required to avoid the wall reflections of the minor lobes in the far-field pattern and their tally-up to the total path-loss, and is realized by a metamaterial lens. This novel structure is designed to be flat and small with resonance frequency of 10 GHz and antenna gain of about 20 dBi from the structure (area of 17cmx17cm and height 5cm). It is adopted to the indoor propagation for a hall-way sized 2.3x4.0x2.7m^3. Path loss becomes lower and the received power becomes -34 dBm much greater than -83 dBm of the FCC path-loss model. Even with the low input power, the wireless link becomes stronger.

II. A NEW ANTENNA FOR PROPAGATION IN A HALL-WAY

The wireless link in a narrow hall way is depicted as below.



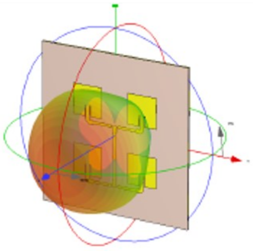
(a)



(b)

Fig. 1. 'Hall-way Indoor wirelessx link of interest (a)3D view (b)Top-view

Unlike the conventional test configuration where a pair of long horns are adopted, the TX is occupied by a planar lens antenna as in Fig. 1(a). The top-view of the situation describes that the TX and RX are placed in a narrow corridor as in Fig. 1(b) and might suffer from multiple wall-reflections severe with lower directivity antennas and 10 GHz lower than 28 GHz. High directivity is achieved by the novel antenna.



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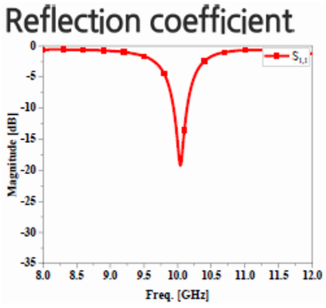

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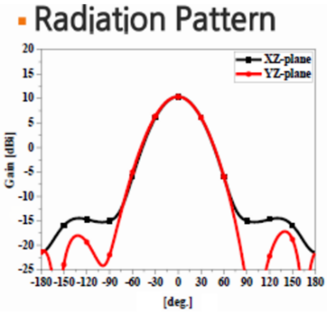

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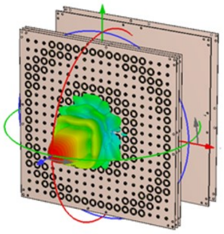
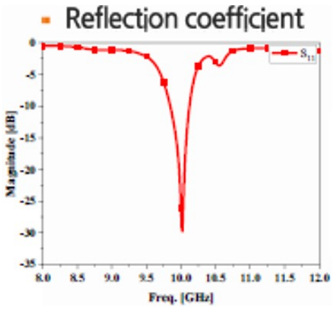


(d)



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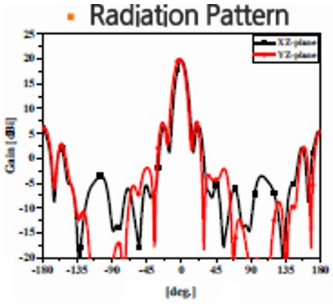
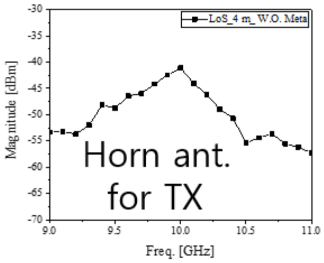


(f)

Fig. 2. A metamaterial antenna (a)Source antenna (b)S_{11} of (a) (c)Beam-pattern of (a) (d) Metasurfce lens added (e)S_{11} of (d) (f)Beam pattern of (d)

Instead of a patch, a 2x2 array is brought as in Fig. 2(a) to help the eventual structure push the limit in antenna gain. It resonates at 10 GHz and typical beam-pattern as in Fig.'s 2(b) and (c). A metasurface lens sized 17 cmx17 cm is placed 5 cm above the source antenna as in Fig. 2(d), which leads to remarkable enhancement in antenna gain by 10 dB at the same frequency. Fig's 2(e) and (f) show the functions as mentioned.

(a)



(b)

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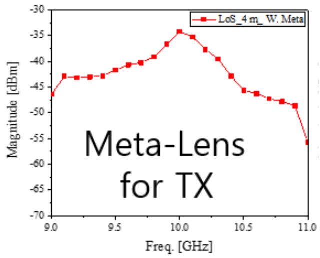


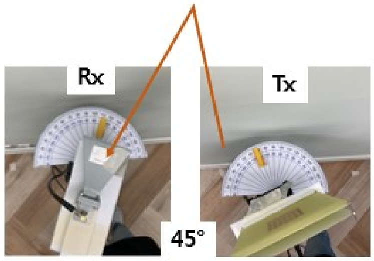
(d)

Fig. 3. Indoor propagation tests (a)Honr-to-horn (b)RX power of (a) (c)Horn-to-metamaterial lens antenna (d)RX power of (c)

As practiced in mm-wave communication networking, high directivity of the radiated field is helpful in making up for path loss which is proportional to the frequency. There are two tests of 10 GHz link on the LOS. Fig. 3(a) has the horn antenna for both the TX and RX. The received power at the frequency of interest is around -41 dBm as in Fig. 3(b). When the TX is replaced by the metamaterial lens antenna as noted in Fig. 3(c), the RX power comes to increase to around -34 dBm as in Fig. 3(d). According to the following formula, the path loss is estimated.

$$PL[\mathrm{dB}]=20log_{10}(\mathrm{freq.}[\mathrm{MHz}])+22log_{10}(\mathrm{distance}[\mathrm{m}])-28 \quad (1)$$

This renders 93 dB as the PL and means -83 dBm when 10 dBm is assumed as the input power. A huge factor of compensation is acquired by the use of the design method.



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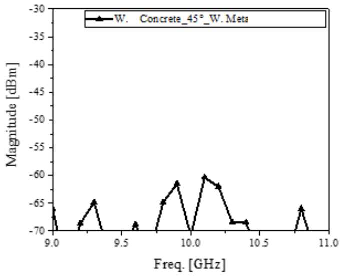

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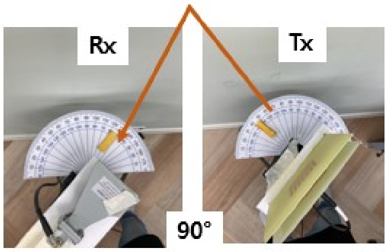

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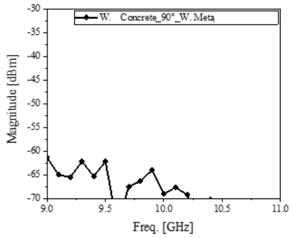

(d)

Fig. 4. RX power of the reflected fields (a)Reflected angle of 22.5° (b)RX power of (a) (c) Reflected angle of 45° (d)RX power of (c)

Indoor propagation modelling goes through reflections from the walls. Actually, the proposed antenna produces the high directivity beam which has a very good SLL. This implies that the influence of the reflected fields included in the multi-paths will be negligible despite being laid in a narrow hall-way. 45° and 90° are selected as doubling of the angles of reflection. Fig.'s 4(a) and (b) are the test setup and received power. It is -60 dBm. The inner angle gets wider as in Fig. 4(c), and the RX power goes down to -68 dBm. All they cannot influence the direct path, in other words, LOS..

III. CONCLUSION

Indoor propagation was experimented on high-frequency band wireless links implemented by a metamaterial lens combined antenna. Small and less expensive as it is, its form-factor and directivity outperforms the conventional antennas for mm-wave communication networking. Not only theoretical part but also experimental part reveals that the properties of the high gain and narrow beam can strengthen the signal from the TX antenna by beating the problems of the narrow hall-way such as multiple reflections and increase in path loss. The received power of -34 dBm sheds a light on the high likelihood of compensating for path loss in indoor mobile communication.

ACKNOWLEDGMENT

This work was supported by the Technology Innovation Program (Project Code: 20016463) funded By the Ministry of Trade, Industry & Energy(MOTIE, Korea).

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