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Leaky wave cable with integrated adjacent antennas in office installation

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Abstract

In this paper leaky wave cable with adjacent antenna elements operated on 3.5 GHz were evaluated by measurement of indoor installed setups. Novel radiation cable arrangements were compared with conventional LCX cable and hot spot antenna references. The power distribution in a 34 m long office environment was measured using a leaky coaxial cable (LCX) with several antennas having either low (-6,7 dB) or high (+2 dB) gains and compared with a conventional LCX and hot spot antenna solutions. Presented novel LCX cables provided a well distributed EM field along the corridor, presenting the best performance after 10 m distances from the transceiver and the field was 30 dB stronger than hot spot antenna`s at the end of the corridor. LCX cable performance was improved prominent 8 dB. The solution can be utilized in the construction of evenly distributed and reliable indoor coverages or power fields for energy harvesting with competitive implementation costs.

1. Introduction

Electromagnetic wave propagation and indoor network properties for telecommunication purposes have been under investigations for a long time. Previously the interest has been in the 1-10 GHz commercial bands and more recently in the E-Band 71-76 GHz and 81-86 GHz, which can potentially provide over 1 Gbps data rate full-duplex throughput [1]. Moreover in [2], 28 GHz signal indoor-outdoor measurements revealed a strong reflectivity of external building materials and low attenuation of indoor materials that could also help in reducing interference between indoor and outdoor mm-wave networks. In [3], a 15 GHz signal with 1 GHz bandwidth was used for measurements of a corridor channel whereas in an earlier research, measurements in an office environment were performed using the 2.4 GHz, 5.25 GHz, 10 GHz, 17 GHz and 24 GHz bands [4]. Both line-of-sight (LOS) paths on the hallway and non-line-of-sight (NLOS) paths were evaluated between distances of 3 – 33 m, those being very common in office environments.

Leaky coaxial cables (LCX) are known for their capability to distribute radio waves in tunnels, e.g., subways and mines [5]. In addition, leaky coaxial cables have also been studied in an underground transportation system [7], in a mobile communications application in buildings [8, 9, 10], as a surveillance sensor [11], and in RFID (Radio Frequency IDentification) [12]. Recently the propagation and radiation properties of coaxial cables with a multi-angle multi-slot configuration have been studied in [6] demonstrating the advantages of controllable radiation and low longitudinal attenuation. In addition, recent research in this field has covered distributed antenna networks and LCXs [13] and MIMO-LCX applications [14-16]. They are typically operating under 10 GHz frequency. There are still some unknown slots in the field of indoor radio signal propagation below 10 GHz, and especially LCX cable systems are interesting available option for indoor telecommunication solutions.

In this article the RF power performance of 3,5 GHz (band 42) of LCX cables with various distributed antenna solutions were evaluated in a 34 m long office environment and compared with corresponding hot spot antenna implementation. This is a case study emphasizing new adjacent antenna solution on LCX cable and their RF performance. Comparing presented LCX resonator cable structures to existing distributed antenna networks is the phenomenon to integrate antenna element as a part of cable structure.

2. Experimental setup and simulated antenna structures

2.1 LCX cable structure with adjacent antennas

The principle of three antenna types that were compared together are presented in Figure 1. The first one is typical spot antenna radiating either directive or indirective fields. The second is typical radiation cable radiating either wide band (coupling type) or narrow band (periodic radiation type) manners. In this paper, wide band LCX cable was used as a reference. The LCX cable is improved by installing a monopole antenna on top of LCX cable, on the orientation where continuous outer conductor openings are located (Figure 2, left). It is called low gain antenna. The antenna element couples energy from cable through continues openings and then radiates it perpendicular to the cable surface. On the other hand antenna element couples energy from cable and then couples it to the mode that is propagating parallel outside the LCX cable. In order to increase coupling coefficient between the antenna element and the cable certain physical opening (20 mm x 50 mm) is done on the outer conductor. Installing the same monopole antenna on top of opening for 1 mm cable to antenna distance, the high gain antenna element is comprised (Figure 2, right). LCX cable with the opening is presented on the roof of corridor in Figure 3. Thus antennas presented in Figure 2 were installed on cable outer surface for 6 m periods as presented in Figure 1, as 6 m periods. Wave periodicals were not measured since the distance between two elements is about 60 wavelengths. Now the LCX cable with 6 pcs of low gain (-6,7 dB) antenna elements was installed on roof of 34 m long corridor. It was changed to LCX cable with 6 pcs of high gain (2,0 dB) antenna elements in another measured case. The LCX cable with adjacent antennas represents simplified radiation package structure and it is possible to adjust the output power and radiation direction by changing the antenna element and the size of opening on the cable. The component structure provides novel way to build indoor networks.

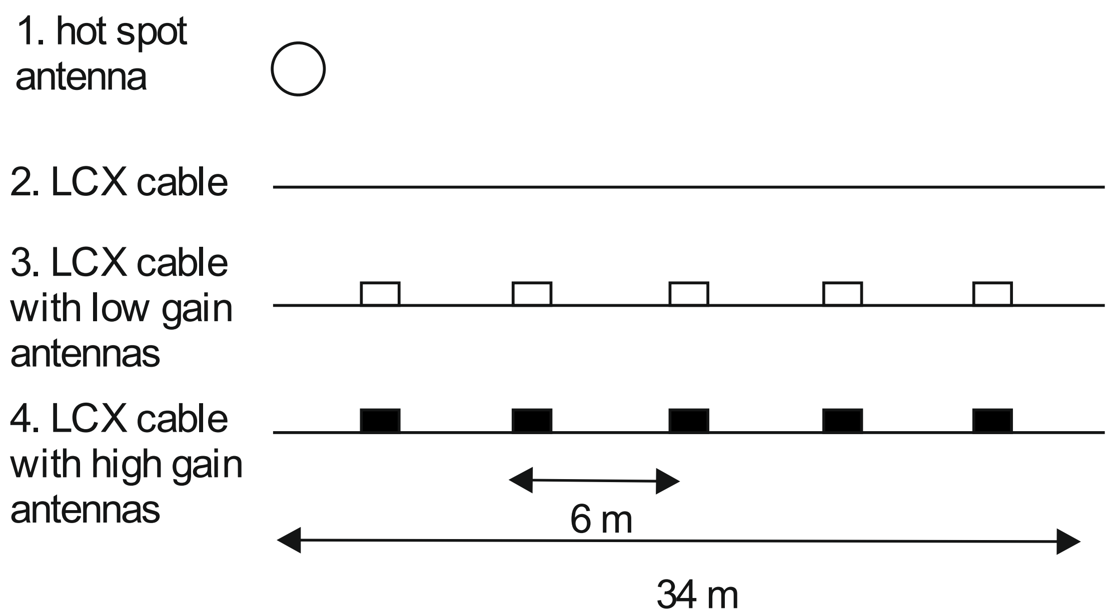

Figure 1. Hot spot antenna (1), conventional LCX cable (2), LCX cable with low gain antennas (3), and LCX cable with high gain antennas (4).

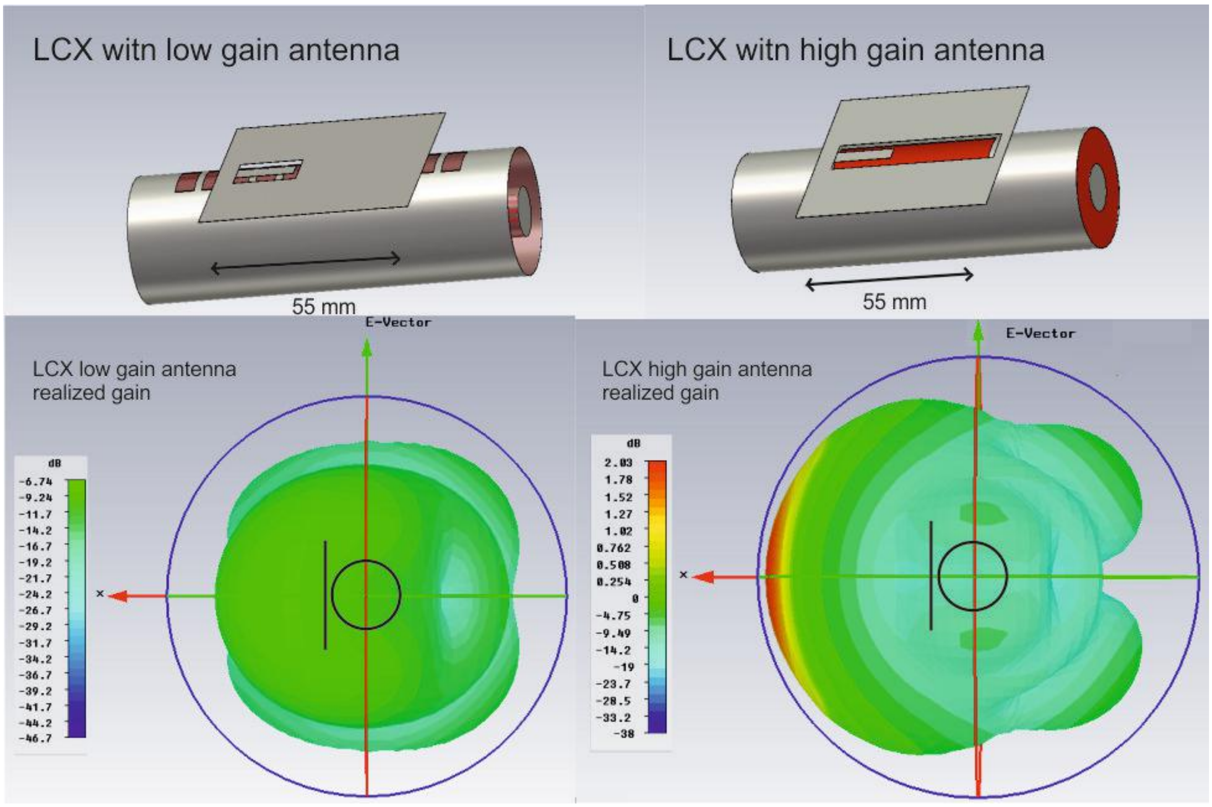

Figure 2. LCX with low gain antenna (left) and high gain antenna (right). Realized gains calculated (below) for evaluated setups. Antenna elements have 55 mm x 40 mm dimensions and they were located on continuous openings (left) or large opening (20 mm x 50 mm).

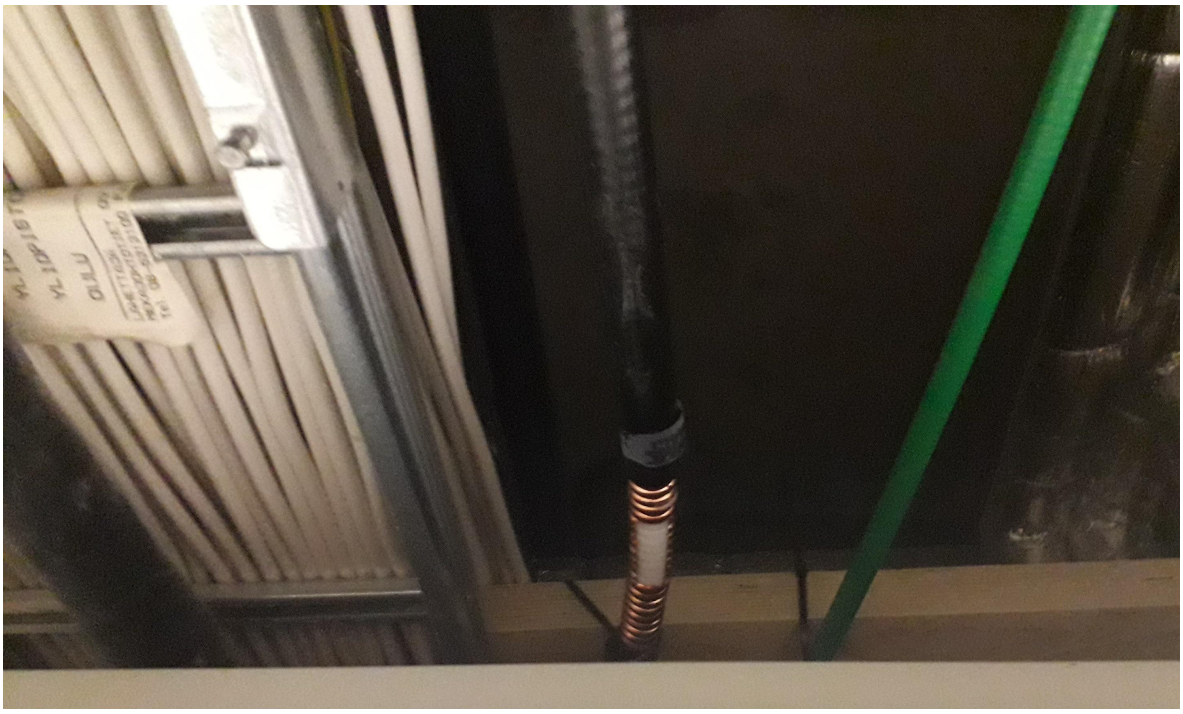

Figure 3. LCX with manually made physical outer conductor opening (20 mm x 50 mm) where monopole antenna was later installed.

2.2 *LCX cable structure with adjacent antennas*

LCX cable measurements were performed along 34 m long corridor (Figure 4) with offices distributed along it. The office map is presented in Figure 5, where the corridor width is 2m and rooms either 4 m or 6 m long. Measurements were carried out with a moving station consisting of a 20 GHz vector network analyser and a monopole antenna located at 1 m height (Figure 6) that was moved along the LCX cable installation in the middle of the corridor. Single carrier frequency was used and transmitted signal power level was stored at certain locations. In this paper only corridor just under the cable setups were measured but not rooms since the goal was to compare instant performance differences between LCX cables.

Figure 4. The corridor where LCX cables with adjacent antenna elements were installed behind the white roof (wool) materials. Antennas and cable openings were directed downwards providing energy to corridor and rooms on its two sides.

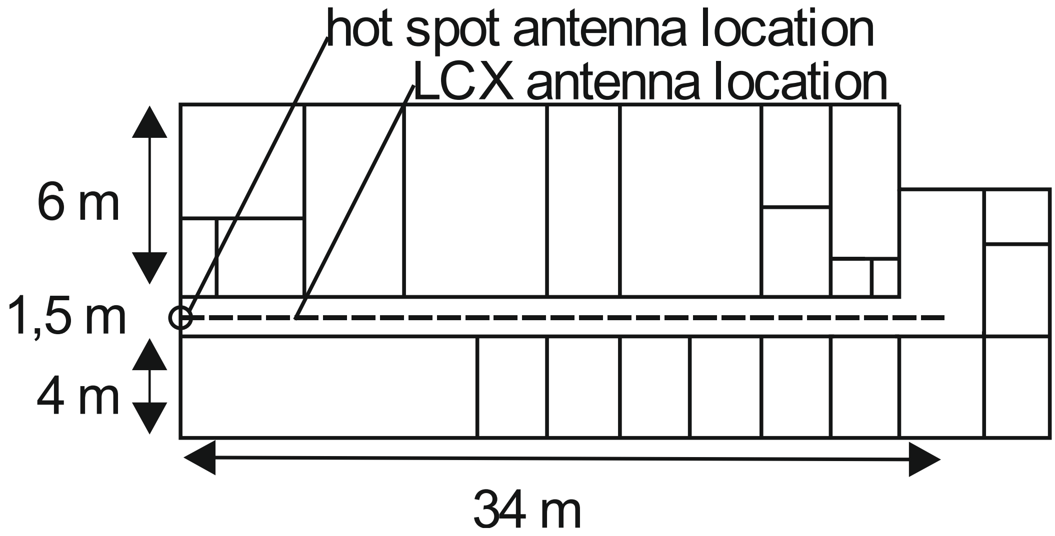

Figure 5. Office layout of measurement area consisted of a 34 m long and 2 m wide corridor with 6 m by 4 m offices. Measurement route along the corridor is marked as a dotted line.

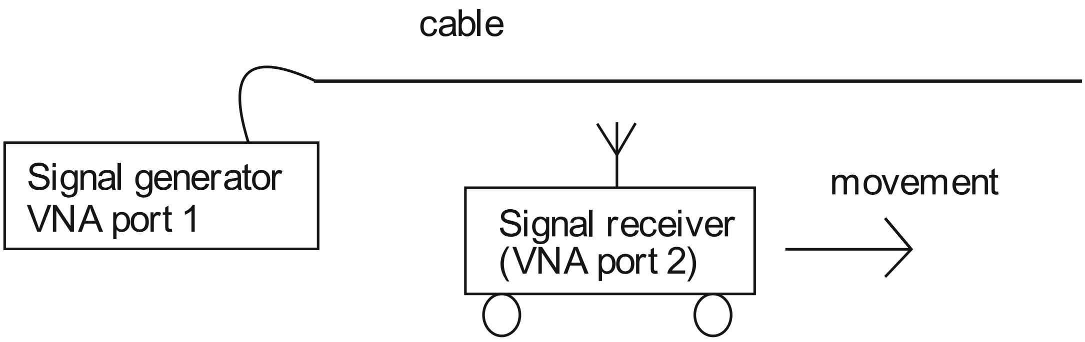

Figure 6. Measurements performed with 20 GHz VNA and antenna. VNA port1 on the LCX cable and port2 on the receiver antenna. Receiver antenna was moved along the LCV cable installation.

3. Measurement results and discussion

LCX cable performances are reported as coupling loss measurement results from the corridor were cable components were installed. The results are presented in Figure 7.

In the case 1 reference, with the commercial discrete antenna (Pulse electronics) the measured coupling loss maximum was -62 dB in the beginning of the corridor and it decreased to -93 dB at the end of corridor. It reached the lowest level as fast as 21 m of distance that was the worst measurement result with all cases even though the antenna was directed on the corridor.

The case 2, with conventional coupling mode LCX cable (Prysmian group) it provided coupling levels from -66 dB and -67 dB at two high peaks at 12 m and 24 m of distances. In the end of corridor the coupling was -82 dB. The coupling performance was clearly better with the commercial LCX cable than with the hot spot antenna.

The case 3, LCX cable equipped with 5 pcs low gain (-6,7 dB) antenna radiators with a 6 m distance between each element provided coupling levels from -66 dB to -70 dB. The LCX with the low gain antennas coupling values were on average 4 dB higher than with conventional LCX cable.

The case 4, LCX with 5 pcs high gain (+2 dB) antenna radiators also with 6 m distances provided coupling levels from -63 dB to -66 dB. Measured performance was the best of all cases and it was on average 4 dB higher than with LCX cable with low gain antennas and 8 dB higher than conventional LCX cable. 8 dB is prominent improved value and it would be very likely to improve radio system performance in the environment.

In the current office environment at 3.5 GHz the LCX provided much higher performance compared to the corresponding hot spot solution at over 10 m distances calculated from the feed point and even 30 dB higher power levels at the end of the 34 m long corridor. Improved LCX cable technology would provide flat power distribution that is beneficial for economical, data distribution [17] and radiation health points of views. The coupling improvement is remarkable and it would open even more interesting results in the future when SAR values emitted from network devices are widely investigated.

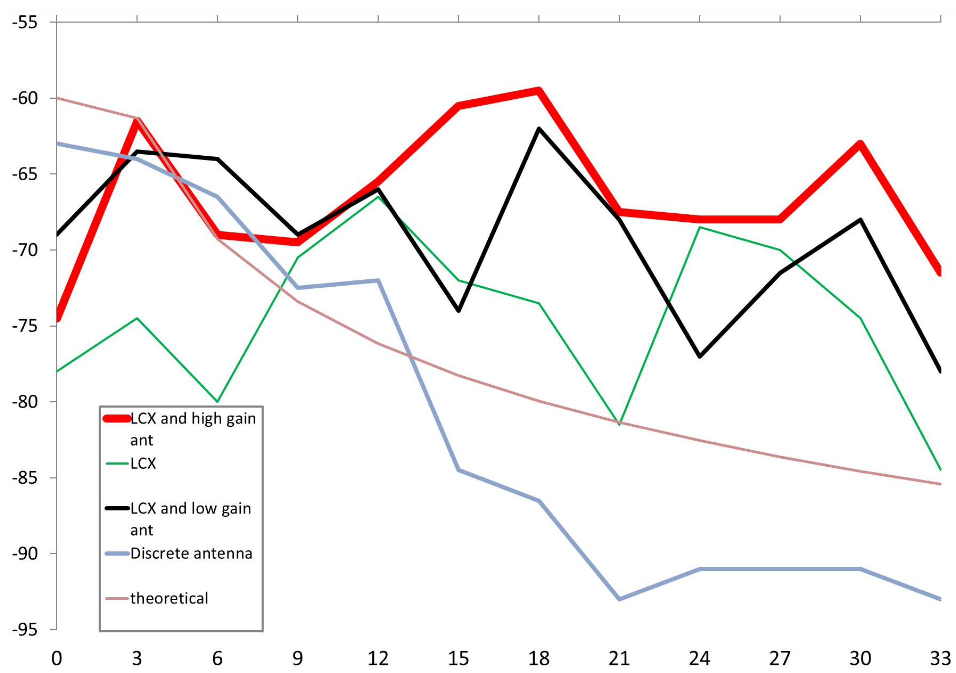

Figure 7. Coupling loss measurements and calculations with LCX antennas operating at 3.5 GHz frequency in an office environment.

Conclusion: In this paper leaky wave cable with adjacent antenna elements operated on 3.5 GHz were evaluated by measurement of indoor installed setups. Novel radiation cable arrangements were compared with conventional LCX cable and hot spot antenna references. The power distribution in a 34 m long office environment was measured using a leaky coaxial cable (LCX) with several antennas having either low (-6,7 dB) or high (+2 dB) gains and compared with a conventional LCX and hot spot antenna solutions. Presented novel LCX cables provided a well distributed EM field along the corridor, presenting the best performance after 10 m distances from the transceiver and the field strength was 30 dB stronger than with hot spot antenna`s at the end of the corridor. LCX cable performance was improved prominent 8 dB. The solution can be utilized in the construction of evenly distributed and reliable indoor coverages or power fields for energy harvesting with competitive implementation costs..

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