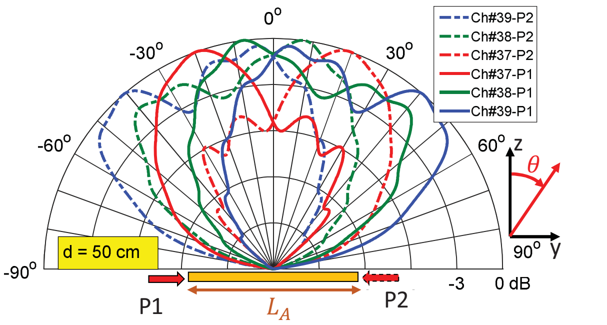

Fig. 3. Angular power distribution of the FFF LWA at a near-filed distance of d=50 cm for the three BLE channels.

IV. Near-Field Focused Design

Focusing techniques are well known from the point of view of antenna design [10]. The synthesis of a focus was reported in [11], [12], but there was not reconfigurability of the position of the focal point. LWAs offer the capacity to easily synthesize a focus by tapering the structure. Besides, the focus of NFF LWAs can be scanned by changing the feeding frequency, as demonstrated in [13]–[15]. Another way to control the focal position with LWAs is by using electronic scanning [16], but this requires a complex control network. Moreover, the combination of this two techniques was proposed in [17] for 2-D scanning of a focus.

With the aim of creating defined directive beams in the near-field region, a NFF LWA with a focal point at d=50 cm from the antenna and similar aperture length L_A=76 cm than the previous FFF LWA is designed using the synthesis technique of [13]. The power distribution in the vicinity of the antenna is plotted in Fig. 4. Now, it can be clearly seen that a well-defined directive beam is scanned at this close distance of 50 cm for the three design BLE frequencies. The angular cut represented at d=50 cm (purple line) is plotted in Fig. 5a. Six well-defined directive beams are synthesized at this short distance, covering a wide FoV of 50º, as it was done for a large distance in the FFF LWA design in Fig. 1a. Similarly, the six directive beams can be compared to obtain the corresponding five monopulse functions, which are represented in Fig. 5b. The beams at channels #37 and #38 in Fig.5a overlap more than in Fig.3, since the scanning of a near-field beam is not necessarily the same as the one of a far-field beam. This affects the slope of the near-field monopulse function when comparing channels #37 and #38. Despite this, the monopulse technique can be used to properly estimate the DoA with high resolution at a near-field distance of d=50 cm (well in the Fresnel zone of a large aperture L_A=76 cm), which cannot be obtained with a FFF design.

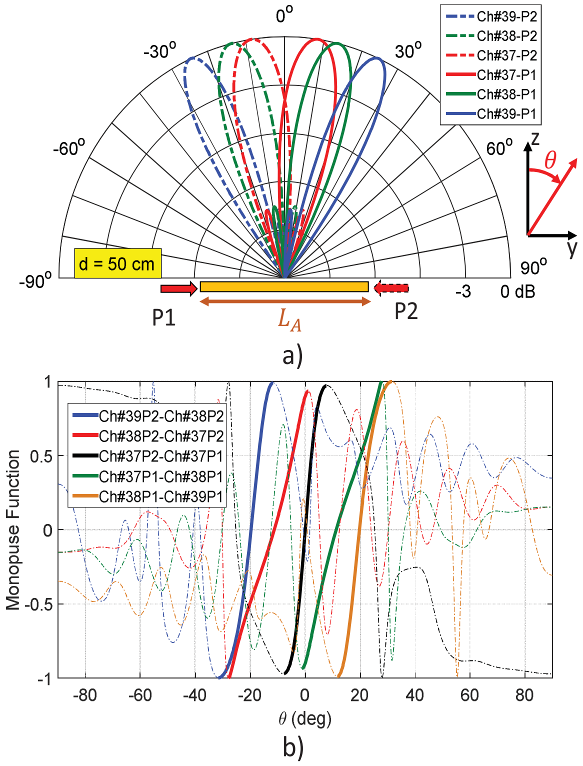

Fig. 5. a) Angular power distribution of the NFF LWA at a near-filed distance of d=50 cm for the three BLE channels. b) Synthesized monopulse functions at 50 cm with this NFF LWA.

Lastly, it is important to evaluate the performance of the NFF LWA design in the far-field region. For this, the frequency-scanned far-field patterns of the NFF LWA are depicted in Fig. 6. As it can be seen, due to the field divergence far from the focal distance of d=50 cm, the patterns are defocused in the far field zone. As a result, broad tilted beams with high secondary lobes are observed in Fig. 6, and they are not suitable anymore for directive monopulse

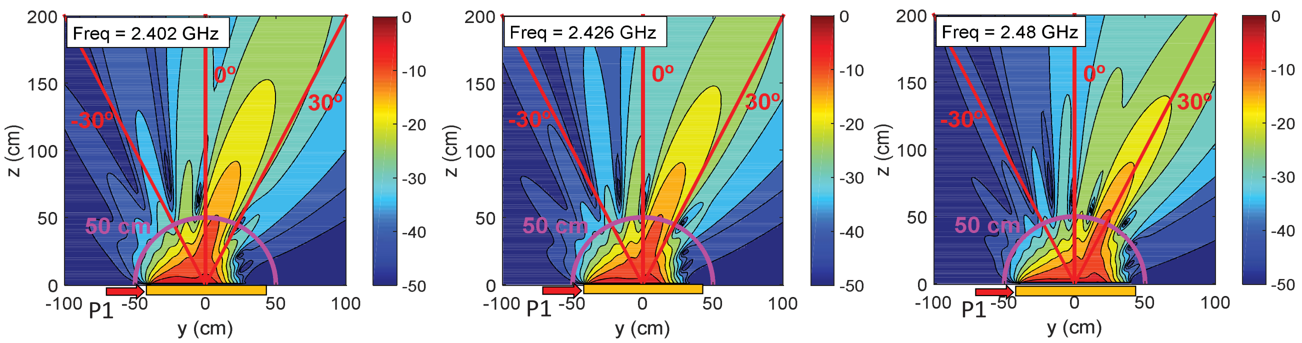

Fig. 4. Near-field region power distribution of the NFF LWA for a) BLE channel #37 b) BLE channel #38 c) BLE channel #39.

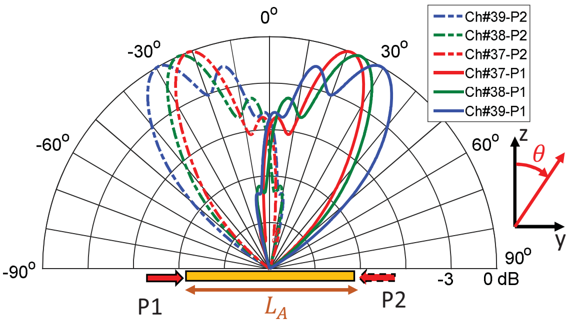

Fig. 6. Far-field frequency-scanned beams of the NFF LWA for the three BLE channels.

pattern synthesis. This effect is expected, since near-field focusing techniques are also used to synthesize broad beams in the far field, as explained in detail in [18]. For this reason, the NFF LWA is a good candidate for proximity applications, but cannot be used for far-field applications. Reciprocally, FFF LWAs are not valid for near-field applications. This trade-off is more significant for longer antennas. Thus, large antennas with potential high directivity must be properly focused at the requested focal distance, in order to avoid loss of angular accuracy due to unwanted broaden of the beams.

V. Conclusion

The unwanted effects when working in the Fresnel region of a far-field focused, frequency-scanning, monopulse leaky-wave antenna, have been evaluated for the first time. It has been shown that the directive scanning performance is strongly degraded in the proximity of the antenna aperture. To overcome this problem, the use of a frequency-scanning leaky-wave antenna focused in the near-field radiative zone, has been proposed and validated with theoretical results. The design demonstrates well-defined scanned directive beams in the vicinity of the antenna. This allows for high-resolution direction-of-arrival estimation in a wide angular area for proximity sensing applications.

The scanning antennas have been designed to operate with the three advertising channels of BLE beacons in the 2.4 GHz ISM band, to demonstrate its applicability for practical wireless location systems. A wide field-of-view of 50º at a short distance of d=50 cm (well in the Fresnel zone of a large aperture L_A=76 cm), has been scanned with six directive beams. This directive angular performance for proximity-location applications cannot be obtained with a far-field focused design. Moreover, the focal distance must be adequately chosen to avoid undesired divergence of the beams, which reduces the angular detection accuracy.

Acknowledgment

This work has been supported by Spanish National project TEC2016-75934-C4-4-R.

References

[1] J.-C. Wu, C.-C. Chang, T.-Y. Chin, S.-F. Chang, M.-C. Chiu, C.-Y. Hsu, and R.-H. Lee, "Wireless indoor localization using dynamic monopulse receiver," *Radar Conf. (EuRAD), 2010 Eur.*, pp. 69–72, 2010.

[2] M. Del Prete, D. Masotti, N. Arbizzani, and A. Costanzo, "Remotely identify and detect by a compact reader with mono-pulse scanning capabilities," *IEEE Trans. Microw. Theory Tech.*, vol. 61, no. 1, pp. 641–650, 2013.

[3] J. L. Gomez-Tornero, D. Canete-Rebenaque, J. A. Lopez-Pastor, and A. S. Martinez-Sala, "Hybrid Analog-Digital Processing System for Amplitude-Monopulse RSSI-Based MIMO WiFi Direction-of-Arrival Estimation," *IEEE J. Sel. Top. Signal Process.*, vol. 12, no. 3, pp. 529–540, 2018.

[4] J. A. Lopez-Pastor, A. Gomez-Alcaraz, D. Canete-Rebenaque, A. S. Martinez-Sala, and J. L. Gomez-Tornero, "Near-Field Monopulse DoA Estimation for Angle-Sensitive Proximity WiFi Readers," *IEEE Access*, vol. 7, pp. 88450–88460, 2019.

[5] M. Poveda-Garcia, D. Cañete-Rebenaque, and J. L. Gomez-Tornero, "Frequency-scanned monopulse pattern synthesis using leaky-wave antennas for enhanced power-based direction-of-arrival estimation," *IEEE Trans. Antennas Propag.*, vol. 67, no. 11, pp. 7071–7086, 2019.

[6] M. Poveda-Garcia, A. Gomez-Alcaraz, D. Cañete-Rebenaque, A. S. Martinez-Sala, and J. L. Gomez-Tornero, "RSSI-Based Direction-of-Departure Estimation in Bluetooth Low Energy Using an Array of Frequency-Steered Leaky-Wave Antennas", *IEEE Access,* vol. 8, pp. 9380-9394, Jan. 2020.

[7] "Bluetooth Special Interest Group. (2018). Bluetooth 5.0 core specification." https://www.bluetooth.com/specifications/bluetooth-core-specification/bluetooth5.

[8] A. A. Oliner and D. R. Jackson, "Leaky-Wave Antennas," in *Antenna Engineering Handbook*, 4th ed., J. L. Volakis, Ed. New York: Mc-Grow-Hill, 2007.

[9] C. A. Balanis, *Antenna Theory: Analysis and Design*, 3rd ed. New Jersey: Wiley-Interscience, 2005.

[10] P. Nepa and A. Buffi, "Near-field-focused microwave antennas: Near-field shaping and implementation," *IEEE Antennas Propag. Mag.*, vol. 59, no. 3, pp. 42–53, 2017.

[11] H. T. Chou, T. M. Hung, N. N. Wang, H. H. Chou, C. Tung, and P. Nepa, "Design of a near-field focused reflectarray antenna for 2.4 GHz RFID reader applications," *IEEE Trans. Antennas Propag.*, vol. 59, no. 3, pp. 1013–1018, 2011.

[12] A. Buffi, A. A. Serra, H.-. T. Chou, and G. Manara, "A near-field focused planar microstrip array for 2.4 GHz RFID readers," *ISAP 2016 - Int. Symp. Antennas Propag.*, vol. 58, no. 5, pp. 758–759, 2017.

[13] J. L. Gomez-Tornero, F. Quesada-Pereira, A. Alvarez-Melcon, G. Goussetis, A. R. Weily, and Y. J. Guo, "Frequency Steerable Two Dimensional Focusing Using Rectilinear Leaky-Wave Lenses," *IEEE Trans. Antennas Propag.*, vol. 59, no. 2, pp. 407–415, 2011.

[14] A. J. Martínez-Ros, J. L. Gómez-Tornero, F. J. Clemente-Fernandez, and J. Monzó-Cabrera, "Microwave near-field focusing properties of width-tapered microstrip leaky-wave antenna," *IEEE Trans. Antennas Propag.*, vol. 61, no. 6, pp. 2981–2990, 2013.

[15] D. Blanco, J. L. Gómez-Tornero, E. Rajo-Iglesias, and N. Llombart, "Holographic surface leaky-wave lenses with circularly-polarized focused near-fields - Part II: Experiments and description of frequency steering of focal length," *IEEE Trans. Antennas Propag.*, vol. 61, no. 7, pp. 3486–3494, 2013.

[16] Y. Monnai and H. Shinoda, "Focus-scanning leaky-wave antenna with electronically pattern-tunable scatterers," *IEEE Trans. Antennas Propag.*, vol. 59, no. 6, pp. 2070–2077, 2011.

[17] P. F. Li, S. W. Qu, S. Yang, and Z. P. Nie, "Microstrip array antenna with 2-D steerable focus in near-field region," *IEEE Trans. Antennas Propag.*, vol. 65, no. 9, pp. 4607–4617, 2017.

[18] J. L. Gomez-Tornero, A. R. Weily, and Y. J. Guo, "Rectilinear leaky-wave antennas with broad beam patterns using hybrid printed-circuit waveguides," *IEEE Trans. Antennas Propag.*, vol. 59, no. 11, pp. 3999–4007, 2011.