Meandered Monopoles for 700 MHz LTE Handsets and Improved MIMO Channel Capacity Performance

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Abstract. *In this paper, we present the design and the measurement of MIMO meandered monopole antennas and the computation of their channel capacity performance. The initial proposed handset-system is composed of a meandered monopole operating in the LTE 700 MHz band, connected to a parasitic radiating element for the upper 2.5 GHz LTE band. Two antennas of the same kind are then closely positioned on the same 120x50 mm² Printed Circuit Board (PCB). A neutralization line connects the two antennas to enhance their port-to-port isolation in the 700 MHz band. The computation of the channel capacity performance in this band is based on propagation simulations performed with the GRIMM model from the CREMANT. Two system-prototypes are evaluated: one with the neutralization line for enhanced port-to-port isolation and a second without the neutralization exhibiting poor antenna-to-antenna isolation. It is demonstrated that the neutralization technique helps in giving a minimum improvement of 12% of the capacity performance of the handset-system, and a maximum improvement 46%, in the chosen environment.*

Keywords

MIMO communications, channel capacity, mobile communications, LTE bands, monopole antennas.

1. Introduction

Modern communication systems require high data rates. To answer this demand, a solution consists in increasing the capacity of the radiofrequency channel between the base station and the handset [1]. One well known technique is the Multi-Input Multi-Output (MIMO) configuration which consists in implementing multiple antennas at both ends of the radio-frequency link. This technology is probably the most established to truly reach the promised transfer data rates of 4G communications [2]. To be more precise, the fourth mobile-phone generation is set to be the Long Term Evolution (LTE) and is scheduled to operate in different bands from 400 MHz to 4 GHz [3].

Modern handsets still experience miniaturization where slim shapes are making difficult the integration of several antennas onto a small PCB [3], [4]. Moreover, position closely-spaced antennas produces high coupling between them. To enhance their isolation, different methods have been adopted [5], [6] but the neutralization line is commonly used in our laboratory [7-12]. In addition, it is necessary to note that modern handsets have to operate in different frequency bands [13]. All these remarks make not a trivial achievement reaching a sufficient isolation in each of these communication bands.

In this paper, we present the design, the measurement and the evaluation of the channel capacity performance of two closely spaced antennas for LTE mobile communication devices. First, a dual band antenna is presented. The antenna consists of a main meandered monopole operating in the 700 MHz band and a parasitic element dedicated to enlarge the higher 2.5 GHz LTE band. Then, two antennas of the same kind are closely positioned on the same PCB. To enhance their port-to-port isolation in the lower band, a neutralization technique is implemented. Scattering parameters, radiations patterns and efficiencies are presented to prove the usefulness of the method. The channel capacity performance is then evaluated in this 700 MHz band with and without the neutralization line between the antennas. It is demonstrated that the minimum benefit of the neutralization technique is 12 % in terms of capacity performance and can even reach 46% for the chosen environment.

2. Antenna Design

In this section, we present the different design stages of the antenna for the MIMO handset-system.

2.1 Single Monopole

First, a single monopole is designed. The layout of the optimized mono-band antenna is presented in Fig. 1.

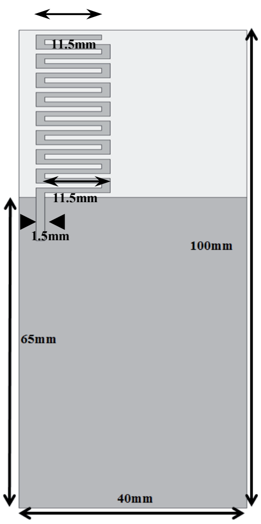

Fig. 1. Top-view of the layout of the single-band monopole.

The monopole is meandered for miniaturization and its average electrical length is calculated to be around a quarter-wavelength at 800 MHz. The antenna is printed on a FR4 substrate (permittivity ε_r of the dielectric is 4.4, loss tangent equals 0.02) and its thickness is 0.8 mm. The total size of the handset is 100×40 mm^2 but only 65×40 mm^2 are metalized. The antenna is placed on the top of the PCB and occupies an area of 35×40 mm^2. The counter-pole ground plane (65×40mm^2) is etched on the other side of the board. The simulated scattering parameters, using HFSS software, are presented in Fig. 2.

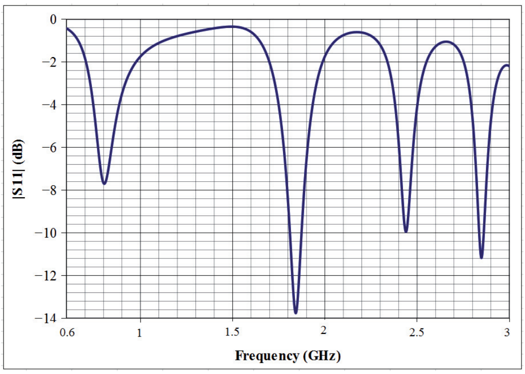

Fig. 2. Simulated reflection coefficient of the single-band monopole.

To be able to efficiently cover the 2.5 GHz LTE band, a parasitic element, connected to a low-impedance region of the monopole, has been optimized to create an additional resonance and enlarge the existing bandwidth (Fig. 3). The electrical length of this element is around a quarter-wavelength at 2.5 GHz, but no further details will be presented in this higher band as the purpose of this paper is to study the MIMO performance of the handset where it is the most difficult, i.e. in the 700 MHz band (see [14], [15] for details).

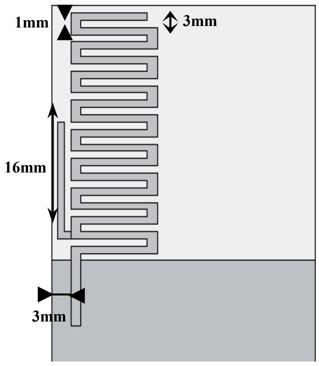

Fig. 3. Top-view of the layout of the dual-band monopole (zoomed-view of the antenna).

2.2 Multi-Antenna System

In a first attempt, the two monopoles have been simply placed at the same top edge of the PCB (Fig. 4). A poor isolation (2.5 dB) was obtained between the feeding port of the monopoles in the 700 MHz LTE band.

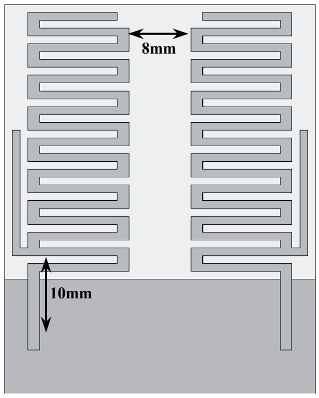

Fig. 4. Top-view of the layout of the initial multi-antenna system (zoomed-view of the antennas).

In order to improve the port-to-port isolation, a neutralization line was simply inserted between both antennas, in a low impedance area of the monopoles where density currents are high and electric fields less important (Fig. 5). A parametric study was conducted on the dimensions (length and width) and the position of the neutralization line to achieve the best isolation value.

First the position of the neutralization line was varied from 2 to 10 mm (see Fig. 5 for the connection point to be positively varied). The optimum value was found to be 6 mm, both for best matching and isolation performance (Fig. 6). At this optimum position, the width of the neutralization line was varied from 0.5 to 2 mm. The optimized structure is pictured in Fig. 7 where the ground plane is cut for battery position.

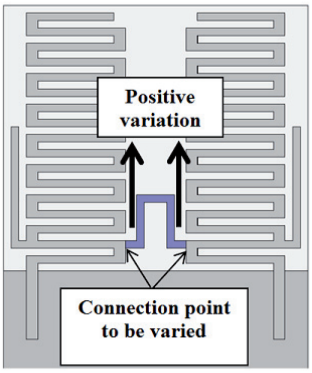

Fig. 5. Top-view of the layout of the neutralized multi-antenna system (zoomed-view of the antennas).

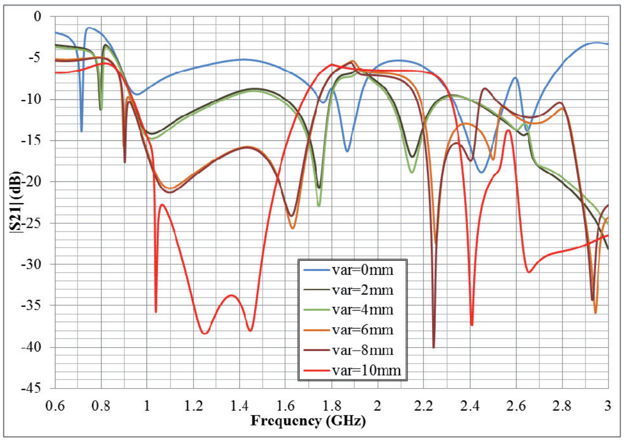

Fig. 6. |S21| versus the position of the neutralization line.

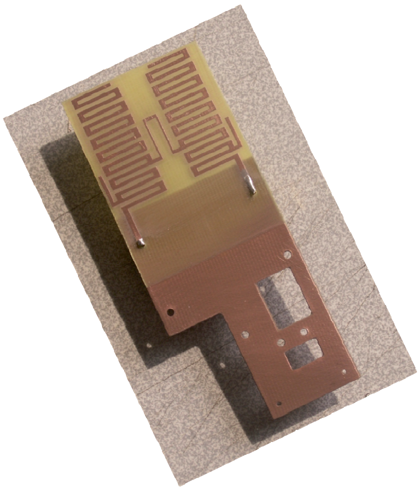

Fig. 7. Picture of the optimized multi-antenna system with the neutralization line. Ground plane is cut for battery position.

Simulated and measured scattering parameters of the two antenna prototypes (with and without the neutralization lines) are respectively shown in Fig. 8 and 9. Simulations and measurements are in good agreement eventhough the simulated resonant frequencies (taken as the minimum of the $|S_{11}|$) are slightly offset from the measurement results. Also, we can see that the resonant frequency of each multi-antenna system is 800 MHz because we anticipated for the detuning that will occur during the integration of the structure into a plastic casing for further outdoor measurements. Both neutralized and non-neutralized systems feature a very good matching. In Fig. 8, the minimum measured isolation parameter $|S_{21}|$ is found to be slightly higher than the simulated one (3 dB versus 2.5 dB). These isolation values are fair poor indicating that a lot of power is lost in the second antenna when the first one is powered-up. In Fig. 9, the port-to-port isolation of the neutralized antenna-system is presented. The measured isolation is now largely higher than 10 dB according to a specific bandwidth or always higher than 6 dB. These values indicate that the two antennas are more isolated and only a small amount of power is lost in their termination. The total efficiency of the two prototypes was measured in a SATIMO chamber: respectively 17.5 % and 45% with and without the neutralization line (more than 50% relative improvement). The critical parameter of this neutralization multi-antenna system for efficient performance is now the reflection coefficient rather than the port-to-port isolation. Dealing with those values, it is expected that high total efficiency will be reached with the neutralized antenna-system and therefore high channel capacity as the injected power in the antennas is all radiated [16], [17].

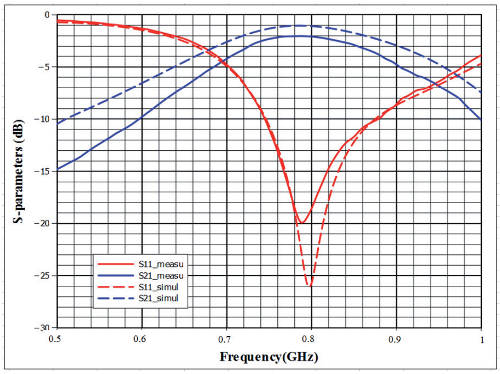

Fig. 8. Simulated and measured scattering parameters of the multi-antenna system without the neutralization line.

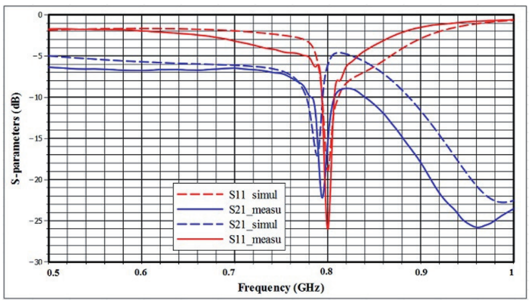

Fig. 9. Simulated and measured scattering parameters of the multi-antenna system with the neutralization line.

3. Performance Test Protocol

In order to test the actual efficiency of these multi antenna systems in a realistic propagation environment, one option is to compute the ergodic maximal capacity as expressed in (1) (see [18]).

$$C = \log_2\left[\det\left(\mathbf{I}_{N_R} + \frac{\rho}{N_T}\mathbf{H}\mathbf{H}^{\mathbf{H}}\right)\right]. \tag{1}$$

In this equation, N_T is the number of transmitters, N_R the number of receivers, $\mathbf{H}$ is the normalized channel matrix whose entries have unit average power, ρ is the average SNR, $\mathbf{I}_{NR}$ the identity matrix of N_R dimension, and $(.)^H$ denotes the complex conjugate transpose. Another way to estimate the channel capacity of the multi-antenna systems is offered by taking the results of the propagation measurements including delay and direction of arrival at both the mobile and the base station [19]. It is then possible to retrieve each element $h_{i,j}$ $(0 \le i < N_T,\ 0 \le j < N_R)$ of the channel H by combining propagation data and the 3D radiation patterns of the antennas on the following way:

$$h_{i,j} = \sum_{r=1}^{R} \overrightarrow{G_{Bi}(\theta_{Br},\phi_{Br})}\,\overline{\overline{A_r}}\,\overrightarrow{G_{Mj}(\theta_{Mr},\phi_{Mr})}\exp\left(2\pi j\vec{x}\cdot\vec{k_r}\right) \tag{2}$$

where the sum is computed over the number R of rays. $\overrightarrow{G_{Bi}(\theta_{Br},\phi_{Br})}$, $\overrightarrow{G_{Mj}(\theta_{Mr},\phi_{Mr})}$ are respectively the polarized amplitude gain of the i^{th} element of the base station and of the j^{th} element of the mobile antenna in the respective direction of departure and incidence of the ray represented by the respective Euler angle (θ_{Br} ϕ_{Br}) and (θ_{Mr}, ϕ_{Mr}), $\overline{\overline{A_r}}$ is the complex polarized channel matrix of the ray r, $\vec{x}$ is the position vectors of the mobile, $\vec{k_r}$ is the wave vector of the ray r, and the dot in $\vec{a}\bullet\vec{b}$ represents the scalar product between vectors $\vec{a}$ and $\vec{b}$.

Multiple advantages exist when using this technique: we can estimate the performance of the antennas with any desired orientation of the mobile and the computation can be reproduced with exactly the same conditions with different antennas or different orientations. It is therefore a fairly approach to compare different antenna-systems.

Because of the lack of reliable Direction-Of-Arrival (DOA) measurements including all the necessary information like polarization and 3D DOA at both the mobile and the base station at 700-800 MHz in the open literature, we propose here to use the simulation results of the propagation model GRIMM (Géométrie et Rayons pour l'Ingénierie Micro-cellulaire Mobile see [21]). This sofware, shown able to compute, in a large area (9 km x 9 km) of a dense urban area, the full set of rays between the base station and any mobile position, including reflection walls, diffraction by building roofs, by block corners and by relief irregularities. These interactions were taken in any order and in number sufficient to reach the convergence, i.e. that is was checked that the result was not modified by additional one. Their amplitude are issuing from rigorous formulation (Fresnel reflexion coefficient, UTD), excepted for vegetation for which empirical attenuation were used. Scattering by wall was also added for the last interaction before reaching the mobile by using [23]. This model have been validated by extensive experiments at the operating frequency of the antenna-systems and shown to be reliable to accurately predict wideband channel capacity estimations [20], [21]. Its capability to predict MIMO performance was validated at 2 GHz by comparison with several results computed from channel measurements [22].

The test zone was chosen in a dense urban area in the centre of Paris (Fig. 10). The base station is placed 7 m over the top of a roof 25 m high. The surrounding buildings have approximately the same height. The base station antenna was composed as standard operational ones of two co-localised elements polarised at +/-45° with vertical and horizontal 3 dB beam width of respectively 5.1° and 62°, and was oriented at 45° in azimuth (i.e. toward north-west). The simulations of the propagation are performed for a set of 56 mobile positions named here Macro Positions (Fig. 11).

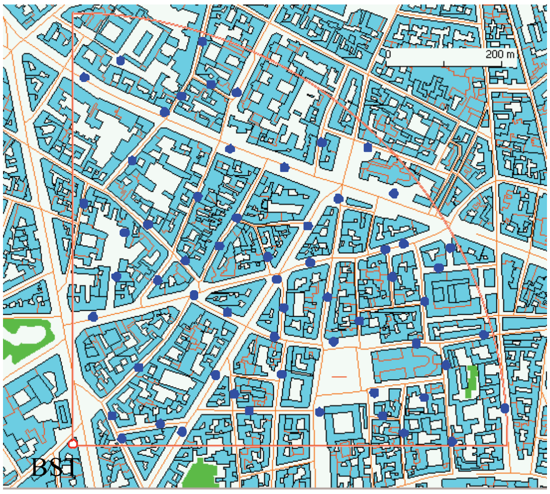

Fig. 10. Map of the testing environment: dense urban area in the center of Paris.

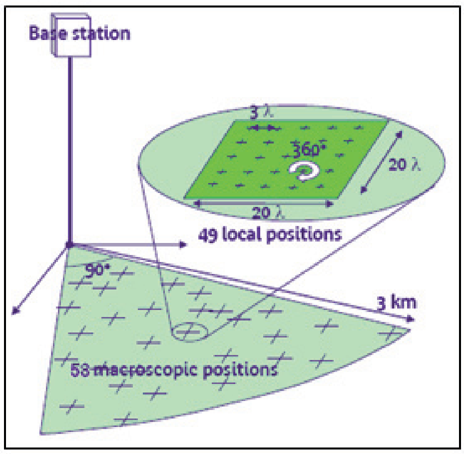

Fig. 11. Testing environment: set of macro-positions of the mobile.

Because of the short-range fading of the channel, the antenna-systems were both moved around the macro-positions with local-positions spanning (20λ x 20λ area with a step of 3λ). In this area, the channel can be considered stationary and the rays are considered as stable. For this reason, between the different local-positions, the same simulated propagation rays are considered ($\overline{\overline{A_r}}$ in (2)) and only their respective phase are changed in function of the geometrical optical path changes (exponential part of (2)). In order to make the simulation results independent of the orientation of the mobile antenna, this one was rotated over 360° with a 30° step.

4. Evaluation of the MIMO Performance

The instantaneous MIMO capacity of both antenna-systems (non-neutralized and neutralized) was computed for all the positions and we extracted the mean MIMO capacity from those computations. These values, presented in Fig. 12 versus different signal to noise levels, clearly show the advantage of the neutralized antenna-systems since we observe a capacity gain ranging from 12% (SNR = 30 dB) to 46% (SNR = 5 dB). Note that the higher improvement is observed for lower SNR's which means that the transmission rate is better improved when the communication conditions are difficult.

In Fig. 13 we present the repartition of the individual MIMO capacity of both prototypes for different SNR's (10 and 20 dB). The increase of MIMO capacity is more important for a SNR of 10 dB than for an SNR of 20 dB, as presented in Fig. 12, but for a SNR of 10 dB, the increase is more important for the larger values of the MIMO capacity while it is almost uniform for a SNR of 20 dB. Again, it is seen the importance of having neutralized antennas with good isolation and high total efficiency.

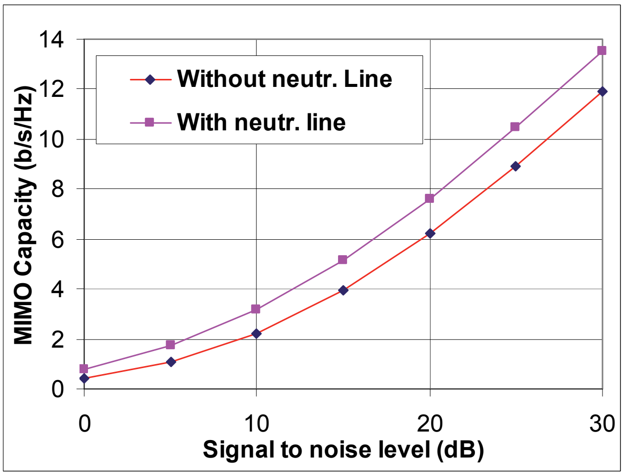

Fig. 12. Mean MIMO capacity over the set of macro-positions for the neutralized and the non-neutralized antenna systems.

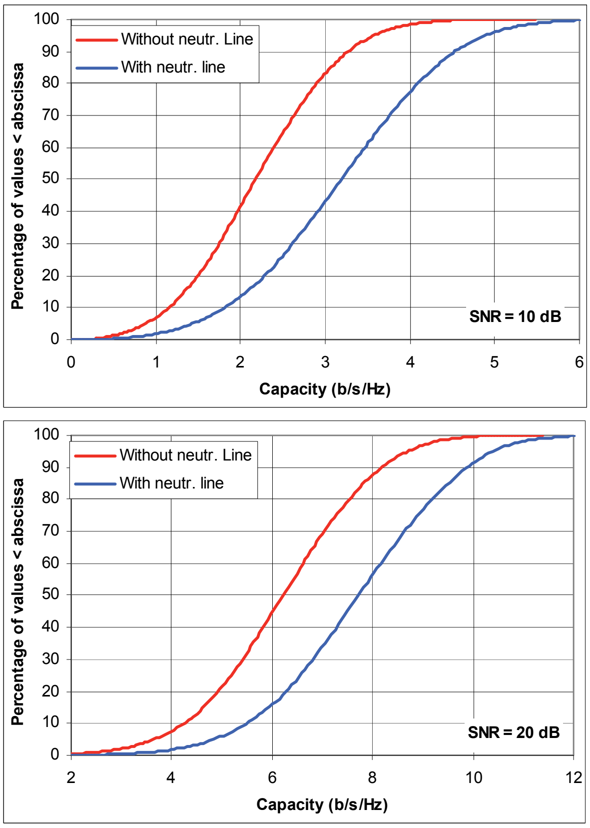

Fig. 13. Cumulative Distribution Function (CDF) of the MIMO capacity of both prototypes for 10 dB and 20 dB SNR's.

5. Conclusion

In this paper, we presented the design and the measurement of neutralized and non-neutralized meandered monopole antennas and the computation of their channel capacity performance. This computation was based on propagation simulations performed with the GRIMM model from the CREMANT. With this tool, it was possible to quantify the contribution of the antennas' performance improvement in terms of Shannon ergodic MIMO capacity. We especially demonstrated that the neutralization technique was helping in giving an improvement of 50% in terms of efficiency; a minimum improvement of 12% of the capacity performance of the handset-system, and a maximum improvement 46%, in the chosen environment. Moreover, the higher improvement was observed for lower SNR's which means that the transmission rate will be better improved when the communication conditions are difficult, which is a very important feature.

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About Authors …

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Mark CLEMENTE was born in Cusco, Peru. In 2005, he received his bachelor degree in Electronics Engineering at San Antonio Abad's University of Cusco. After that, he worked as an engineer in some Telecoms operators in Peru. In 2009, he joined the engineering school of Polytech Marseille in France for a specialisation in Telecommunications and Microelectronics. In 2011, he received the Master degree in Communicating Objects from the University of Provence in France. In September 2011, he joined TELECOM Paristech Institute as a Ph.D student where he works in space electromagnetic transformations and applications in very directive antennas for a European project. His areas of interest are mobile communications, antennas and propagation, satellites, radars and microelectronics, all related to communications.

Aliou DIALLO was born in Dakar, Senegal. He received the DEA degree, specialization in propagation, telecommunications and teledetection in 2004, and the Ph.D in Electronics in 2007 at the Electronics, Antennas and Telecommunication Laboratory (CNRS-LEAT) of the University of Nice Sophia-Antipolis. His major research area is antenna design and measurements methods for wireless communications, and multi-antenna solutions for diversity and MIMO purposes. During his PhD, he has presented several conference papers and he is the co-recipient of the H.W. Wheeler Award of the IEEE Antennas and Propagation Society for the best application paper of the year 2006 of the Transactions on Antennas and Propagation journal. In 2007, he also received the best electronics PhD's prize in France from the club of the professors (teaching and research) in electronics, electrotechnics and automatic. He is also a co-recipient of the best collaboration paper of EUCAP2007. Since 2008, he is an Associate professor at IUT electrical engineering of University of Nice-Sophia Antipolis and researcher at the LEAT (Laboratoire d'Electronique, Antennes et Telecommunications-CNRS UMR 6071) of the University of Nice-Sophia Antipolis, France.

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