# Tunable Decoupling of Tri-band LTE700/GSM850/900 MIMO Antenna with a Parasitic Scatterer for Handheld Devices

Simon Stanev, Alexandru Tatomirescu, Gert F. Pedersen
Department of Electrical Engineering
Aalborg University, DK-9220, Aalborg, Denmark
Email: $\{sstane12\}$ @student.aau.dk, $\{ata, gfp\}$ @es.aau.dk

***Abstract*—This paper presents a simple tunable decoupling mechanism for a tri-band coupled monopole antenna working in LTE700/GSM850/900 bands for MIMO application. A parasitic scatterer with two distributed MEMS tunable capacitors is utilized to match the impedance and mitigate the effects of mutual coupling between elements. Thus, the antenna performance is enhanced significantly by minimizing the coupling current. The prototype is evaluated through the scattering parameters, the total efficiency, the envelope correlation coefficient, radiation patterns, current distributions and fully characterized through simulations. By utilizing a simple passive de-coupling structure, the total efficiency is improved with $1-1.5$ dB and a reduction in the envelope correlation coefficient in the order of $60-75\%$ is obtained over a wide aggregated bandwidth. Due to the change in radiation mechanism for both of the antennas, orthogonal radiation patterns are formed. With this approach, the design of the mobile phone antenna can be simplified by moving to complexity from the antenna to the decoupling structure.**

***Keywords*—long term evolution (LTE), multiple-inpit and multiple-output (MIMO), envelope correlation coefficient (ECC), parasitic scatterer (PS), monopole, mutual coupling.***

## I. Introduction

Nowdays, wireless communication systems require a high data rate to support various multimedia services. Long term evolution (LTE) is the fourth generation (4G) cellular networks, which employs multiple-input and multiple-output (MIMO) antennas in order to achieve a higher data transmission rate and improve the radio link performance [1], [2], [3]. An important requirement for MIMO antenna systems is to have a good isolation between antenna elements. However, in a mobile phone, the antenna elements are naturally strongly coupled with each other below 1 GHz due to closely spaced elements and the common ground plane mode for the induced radiation currents. Thus, it is crucial to mitigate the mutual coupling, which will decrease the envelope correlation coefficient (ECC), increase the total efficiency (TE) and the channel capacity [4].

Many methods have been proposed to mitigate the mutual coupling between antenna elements, such as modifying the ground plane [2], [5] by suppressing of the current flowing between antenna elements. Other methods include decoupling networks [6], polarization decoupling methods [7], [8], [9] and neutralization line technology [11]. Parasitic Scatterer (PS) method is proposed in [12], which acts as a current choke between the two antenna elements and an excellent matching and decoupling can be obtained. In [13] is proposed coupling reduction between PIFAs that utilizes PS. The PS provide an additional coupling path between the PIFAs to cancel out the current from the aggressor antenna to the victim antenna . In [14], two compact narrow-band PIFAs demonstrate a tunable range in the bands from LTE700 to GSM900 with an integrated tunable parasitic element suppressing the coupling between PIFAs by -10 dB across the entire spectrum. In addition, the channel capacity is close to an uncorrelated system. However, the PIFAs are naturally decoupled to -20 dB and the improvement of -10 dB bellow that level is insignificant with respect to the TE and the ECC.

In this paper, a pair of wide-band monopoles antennas are designed for a MIMO application. In contrast to the tunable PIFA in [14], the antennas used in this work are designed to have a low complexity and low ohmic losses. A simple Parasitic Scatterer (PS) tuned by two distributed Micro-Electro-Mechanical Systems (MEMS) tunable capacitors is placed in between the antennas to minimize coupling. By distributing the loading capacitance, the equivalent series resistance (ESR) losses are minimized as in [15]. More precisely, a commercially available tuner can be used [16] that has a tuning range from 0.7 pF to 2.6 pF. Consequently, optimum isolation, increased TE, orthogonal radiation patterns and thus low ECC is achieved by tuning the PS to the desired frequency band of operation.

This paper is organized as follows: Sec. II presents a design of the monopole for MIMO application with simulation results and discussions. Sec. III shows a design example of a PS to mitigate the coupling between elements. Finally, conclusions are made in Sec. IV.

## II. Antenna design and Simulation results

In this section, a design of a simple Monopole Coupled Loop antenna is presented. Further, in order to utilize MIMO, a dual antenna configuration is studied. Fig. 1 shows the geometry of the proposed Monopole Coupled Loop with a) top, b) side and c) bottom view. FR-4 substrate is used with $\varepsilon_r = 4.3$ and dimensions of 118x58x1 $mm^3$. Arlon ISO 933 is used for a casing with $\varepsilon_r = 2.33$ and dimensions of 121x60x7 $mm^3$. Both are with thickness of 1 mm. In addition, a FR-4 substrate with thickness of 0.5 mm is used for robustness of the coupled loop .

Fig. 2 depicts S-parameters of the Monopole Coupled Loop. Where the Monopole (Mon) plus the Coupled Loop (CL) resonate at the 768 MHz with a $-6$ dB bandwidth (BW) of 191 MHz. The CL is excited capacitively through the

Mon and it is grounded through a shorting pin to the system ground plane.

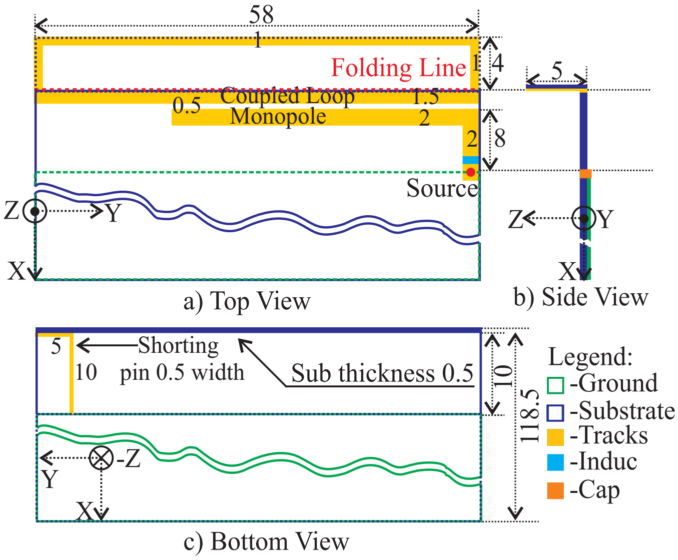



Fig. 1: Geometry of the proposed Monopole Coupled Loop a) Top, b) Side and c) Bottom view with dimensions in mm.

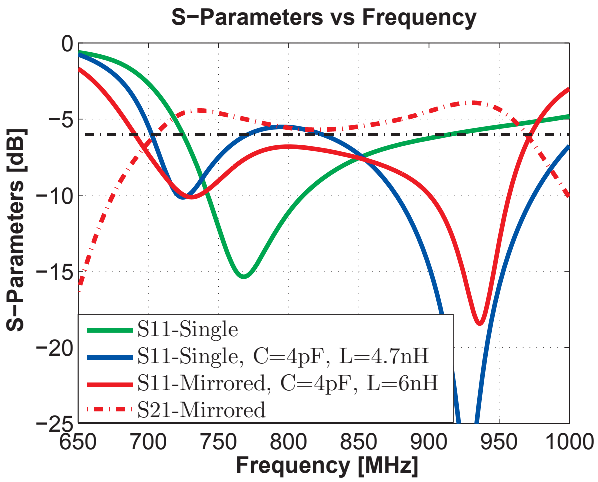


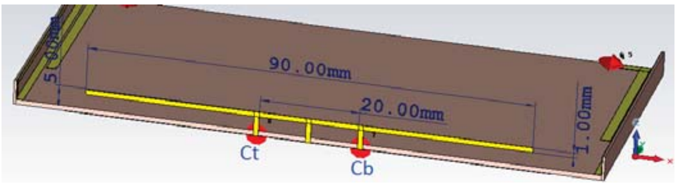

Fig. 2: Comparison of the S-parameters of the Monopole Coupled Loop (Single), Single with a series Inductor (L) and a shunt capacitor (C) and Mirrored with L and C. All scenarios are within a casing.

The Mon and CL will be referred to as a Single element in the rest of the paper. In addition, a matching network consisting of a series inductor (L=4.7nH) and a shunt capacitor (C=4pF) is implemented at the feeding point of the Mon, recall Fig. 1. In order to obtain an acceptable reflection coefficient, a threshold of −6 dB is chosen as a design requirement. As a result, the Single element plus L and C fulfills the requirements for lower mobile band standards which are LTE700/GSM850/900. The ESR has a value of 0.5 Ω for the L and a value of 0.25 Ω for the C. However, in order to support MIMO, a second mirrored identical element is placed at the other end of the Printed Circuit Board (PCB). The red curve from Fig. 2 represents the S-parameters of Mirrored elements. Notice that they are strongly coupled with each other due to small relative distance between elements and the excitation of the same mode of the ground plane. The aim of this work is to suppress this high coupling.

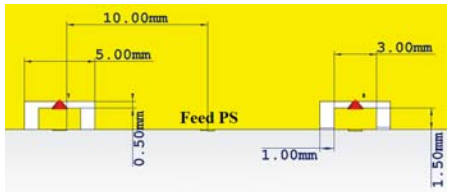
## III. Design of Parasitic Scatterer

In this section, a design example of the Parasitic Scatterer (PS) is shown to mitigate the mutual coupling between antenna elements.

Fig. 3 depicts Geometry of the proposed Parasitic Scatterer (PS) which is positioned at the opposite side of the feed points in the middle of the PCB. The height of PS is 5 mm, the length is 90 mm and the track thickness is 1 mm. The pads for the capacitors of PS are with dimensions 3x1.5 $mm^2$.




(a) Perspective view of (PS)




(b) Bottom view of (PS)

Fig. 3: Geometry of the proposed Parasitic Scatterer (PS) with (a) perspective and (b) bottom view.

Fig. 4 and Fig. 5 show a comparison between the S-parameters in the case of the Mirrored elements with the PS tuned by the capacitors. Notice that when the PS is tuned to a resonant frequency it changes both the input impedance and the mutual coupling of the elements. Additionally, Fig. 5 displays the mutual coupling where the decoupling BW becomes more narrower when the PS is tuned to a lower frequency due to the increase in the Q factor of the PS.

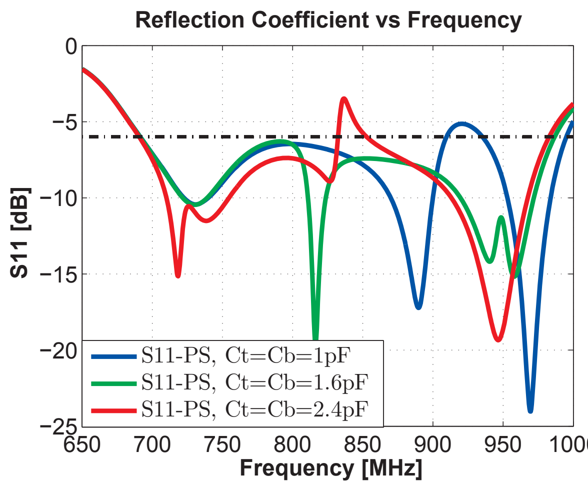



Fig. 4: Comparison between the reflection coefficients in the case of the Mirrored elements with the PS tuned by the capacitors.

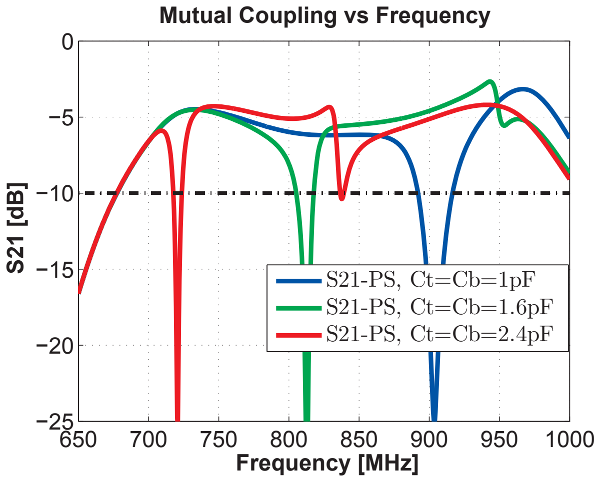



Fig. 5: Comparison between the mutual coupling in the case of the Mirrored elements with the PS tuned by the capacitors.

Fig. 6 illustrates a comparison between the TE in the case with the Mirrored elements without Parasitic Scatterer (NoPS) and in the case with the PS tuned by the capacitors. By increasing the values of Ct and Cb, the PS is tuned to lower frequencies and increases the TE of the MIMO antenna due to the change in the input impedance, mutual coupling and the current distribution on the system ground plane at the tuned frequency. The higher the value of the capacitors, the higher the Q-factor of the PS becomes and thus the BW and the efficiency are decreased. In addition, the dynamic range of the capacitors for the entire tuning spectrum is from 0.7 to 2.6 pF, which could be supported with the current MEMS technology [16]. The sensitivity of the PS and the required tuning range of Ct and Cb can be adjusted by the position of the pads for the capacitors on the ground plane from the shorting point of the PS. The closer they are to the shorting point of PS, the less sensitive it becomes to the capacitance value and thus a larger tuning range is required to cover the same frequency interval.

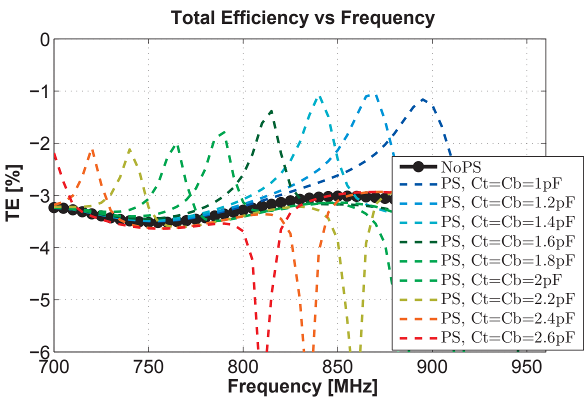
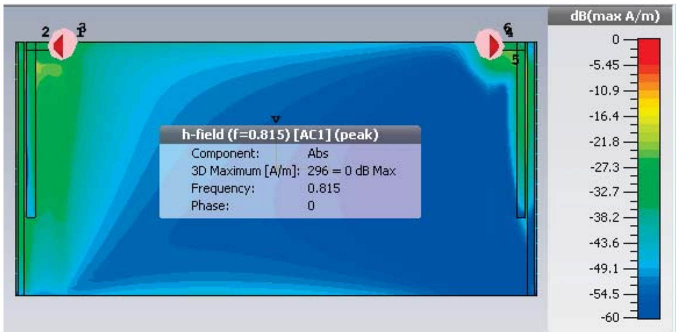
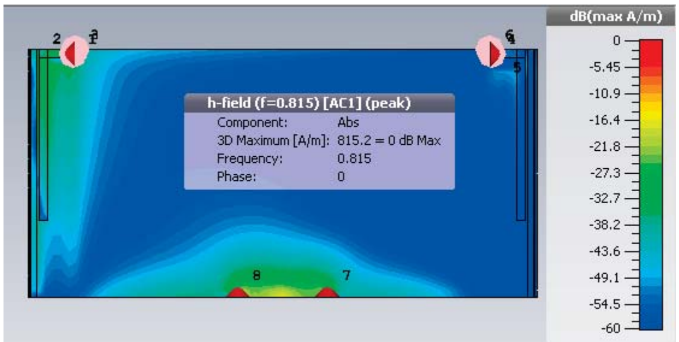



Fig. 6: Comparison between the Total Efficiency (TE) in the case with the Mirrored elements without Parasitic Scatterer (NoPS) and in the case with the PS tuned by the capacitors.

In Fig. 7, a comparison between the current distribution in the case with the Mirrored elements without Parasitic Scatterer (NoPS) and in the case with the PS tuned by the capacitors can be observed. Notice that Fig. 7 a) depicts how strong is the induced current on the adjacent element which leads to reduced TE. However, Fig. 7 b) displays how the surface current distribution has been changed due to the tuned PS placed at middle side of the ground plane.




(a) 815 MHz NoPS




(b) 815 MHz with PS

Fig. 7: Comparison between the current distribution in the case with the Mirrored elements without Parasitic Scatterer (NoPS) and in the case with the PS tuned by the capacitors.

Fig. 8 illustrates a comparison between the Envelope Correlation Coefficient (ECC) in the case with the Mirrored elements without Parasitic Scatterer (NoPS) and in the case with the PS tuned by the capacitors.

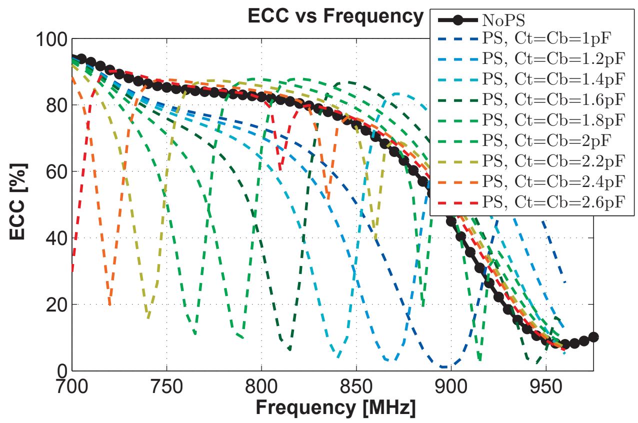
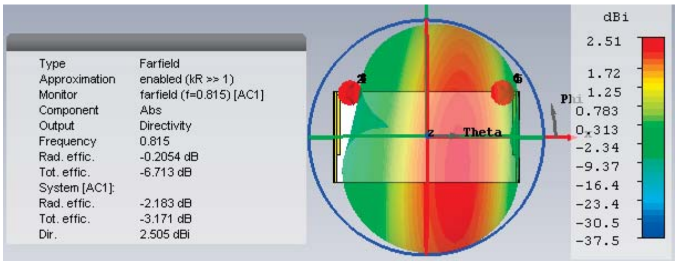



Fig. 8: Comparison between the Envelope Correlation Coefficient (ECC) in the case with the Mirrored elements without Parasitic Scatterer (NoPS) and in the case with the PS tuned by the capacitors.

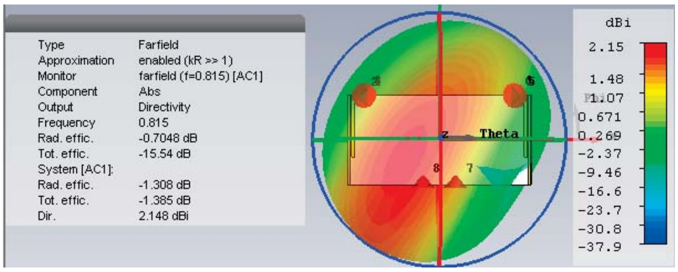
According to [10] ECC for to antenna system requires the 3D radiation pattern and it is computed as follows:

$$\rho_e = \frac{\mid \iint_{4\pi} \overrightarrow{F_1}(\Theta,\phi)\, d\Omega \bullet \overrightarrow{F_2}(\Theta,\phi)\, d\Omega \mid^2}{\iint_{4\pi} \mid \overrightarrow{F_1}(\Theta,\phi)\, d\Omega \mid^2 \bullet \mid \overrightarrow{F_2}(\Theta,\phi)\, d\Omega \mid^2} \qquad (1)$$

where, $\overrightarrow{F_i}(\Theta,\phi)$ is the radiation pattern of the antenna system when port i is excited and • denotes Hermitian product. Eq.(1) assumes isotropic environment and power in the two planes to be independent. In Fig. 8 it is observed that the ECC has reduced significantly but the BW of the ECC becomes narrower when PS is tuned to a lower frequency due to the high Q-factor. Understanding why the ECC in Fig.8 has reduced significantly can be explained by Fig.9 where, a comparison between the radiation patterns in the case with the Mirrored elements without Parasitic Scatterer (NoPS) and in the case with the PS tuned by the capacitors. It is observed how the patterns are changed with the PS which leads to orthogonal radiation patterns compared to those without PS.




(a) 815 MHz NoPS




(b) 815 MHz with PS

Fig. 9: Comparison between the radiation patterns in the case with the Mirrored elements without Parasitic Scatterer (NoPS) and in the case with the PS tuned by the capacitors.

## IV. Conclusion

In this work, it has been shown that the tunable PS enables a good MIMO performance even with a simple antenna design. Since both antenna excite the the dipole mode of the ground plane, they suffer from a high mutual coupling. To mitigated it, a PS is introduced with two distributed MEMS tunable capacitors. Because PS is narrowband and only covers on side of the communication band (Rx or Tx in FDD systems) it has to be tunable. Simulation results show that the PS effectively suppresses the coupling by more than -20 dB in the entire tuning range from LTE700 to GSM900 by modifying the radiation current on the ground plane. As a result, an improvement in the TE with $1-1.5$ dB and a reduction in the ECC witn 60-75% is obtained. Additionally, a change in the radiation patterns is observed. For future work, the PS can be optimized within a given volume, tested with a user interaction, manufacturing the prototype and a comparison between measurements and simulations results for validation purposes.

## References

[1] 3GPP, 3GPP release 13 v0.0.5, 3GPP, Tech. Rep., March 2013.

[2] Yong-Ling Ban, Zhong-Xiang Chen, Zhi Chen, Kai Kang and Joshua Le-Wei Li, "Decoupled Hepta-Band Antenna Array for WWAN/LTE Smarthphone Applications," IEEE Antennas and Wireless Propag. Lett, vol. 13 ,2013

[3] Manoj K. Meshram, Reza K.Animeh, Ankur T.Pimpale and Natalia K. Nikolova "A Novel Quad-Band Diversity Antenna for LTE and Wi-Fi Applications With High Isolation," IEEE Transactions on Antennas and Propagation, vol. 60, No.9, September 2012

[4] David Gesbert, Mansoor Shafi, Da-shan Shiu and Ayman Naguib "From Theory to Practice: An Overview of MIMO SpaceTime Coded Wireless Systems," IEEE Journal on Selected Areas in Communications, Vol.21, No.3, April 2003

[5] J.Zhu, and George V.Eleftheriades, "A Simple Approach for Reducing Mutual Coupling in Two Closely Spaced Metamaterial-Inspired Monopole Antennas," IEEE Antennas and Wireless Propag. Lett, vol. 9 ,2010

[6] Xinyi Tang, Koen Mouthaan and J C. Coetzee, "Tunable Decoupling and Matching Network for Diversity Enhancement of Closely Spaced Antennas," IEEE Antennas and Wireless Propag. Lett, vol. 11 ,2012

[7] Yue Li, Zhijun Zhang and Zhenghe Fend "Design of Dual-Polarized Monopole-Slot Antenna With Small Volume and High Isolation," IEEE Transactions on Antennas and Propagation, vol. 60, No.5, May 2012

[8] Shuai Zhang, Buon K. Lau, Anders Sunesson and Sailing He, A"Closely-Packed UWB MIMO/Diversity Antenna With Different Patterns and Polarizations for USB Dongle Applications," IEEE Transactions on Antennas and Propagation, vol. 60, No.9, September 2012

[9] Shuai Zhang, Andrs A. Glazunov, Zhinong Ying and Sailing He "Reduction of the Envelope Correlation Coefficient With Improved Total Efficiency for Mobile LTE MIMO Antenna Arrays: Mutual Scattering Mode," IEEE Transactions on Antennas and Propagation, vol. 61, No.6, June 2013

[10] Dodney G.Vaughan and J.Bach Andersen, "Antenna Diversity in Mobile Communications", IEEE Trans. Veh. Technol., 1987, pp. 149-172

[11] Aykit Cihangir, Fabien Ferrero, Gilles Jacquemod, Patrice Brachat and Cyril Luxey, "Neutralized Coupling Elements for MIMO Operation in 4G Mobile Terminals," IEEE Antennas and wireless propagation letters, Vol. 13, 2014

[12] B.K Lau, Jrgen B. Andersen, "Simple and Efficient Decoupling of Compact Arrays With Parasitic Scatterers," IEEE Transactions on Antennas and Propagation, vol. 60, No.2, February 2012

[13] Angus C. K. Mak, Corbett R. Rowell, and Ross D. Murch, "Isolation Enhancement Between Two Closely Packed Antenna,." IEEE Transactions on Antennas and Propagation, vol. 56, N. 11, November 2008

[14] Kasra Payandehjoo and Remesh Abhari, "Compact Multi-Band PIFAs on a Semi-Populated Mobile Handset With Tunable Isolation," IEEE Transactions on Antennas and Propagation, vol. 61, No.9, June 2013

[15] Samantha C.D. Barrio and Gert F. Pedersen, "On the Efficiency of Capacitively Loaded Frequency Reconfigurable Antennas," International Journal of Distributed Sensor Networks Vol 2013 (2013),

[16] WiSpry Tunable Digital Capacitor Arrays (TDCA), http://www .wispry.com/products-capacitors.php.