Transactions on Machine Intelligence 5(3) (2022) 152-159

ISSN Online: 2821-1693

Transactions on Machine Intelligence

Journal Homepage: https://tmachineintelligence.ir/index.php/TMI

Mutual Coupling Reduction in Cylindrical Microstrip Array Antenna using DGS

A. Monajati[1,*], N. Safaverdi[2]

[1] Yadegar-e-Imam Khomeini (RAH) Shahre Rey Branch, Islamic Azad University, Tehran, Iran
[2] Department of Electrical Engineering, Yadegar-emam Khomeini branch, Islamic Azad University, Tehran, Iran

ARTICLE INFO

Article History:
Received 4 May 2022
Received in revised form 18 July 2022
Accepted 6 September 2022
Available online 8 September 2022

Keywords:
Component; Conformal Microstrip Antenna, Cylindrical Microstrip Array Antenna, Mutual Coupling Reduction, DGS.

ABSTRACT

This study presents the design and analysis of a three-element cylindrical conformal microstrip patch array antenna that exploits the inherent advantages of cylindrical geometries benefits that are often unattainable with traditional planar antenna configurations. Each array element consists of a rectangular microstrip patch excited by a microstrip line, specifically optimized to resonate at a frequency of 5.3 GHz. A central feature of the proposed design is the integration of a dumbbell-shaped Defected Ground Structure (DGS), strategically employed to suppress mutual coupling effects between the adjacent antenna elements. The inclusion of the DGS structure leads to a notable reduction in mutual coupling measured to be approximately 15 dB without compromising the integrity of the radiation characteristics in both the E-plane and H-plane. Comprehensive simulations of the surface wave distribution further confirm the role of the DGS in diminishing surface wave propagation, thereby enhancing the isolation between elements. Beyond its electromagnetic performance, the antenna design offers several practical advantages, including ease of fabrication, mechanical flexibility, and a compact, low-profile form factor that makes it suitable for integration into conformal platforms such as aircraft fuselages or wearable systems. The results indicate that the proposed antenna structure not only achieves efficient inter-element isolation but also maintains desirable radiation properties, marking it as a promising candidate for modern wireless and radar communication applications requiring compact, conformal, and high-performance antenna arrays.

1. INTRODUCTION

Mutual coupling effects play a significant role in various applications, with potential consequences such as scan blindness in phased arrays with extensive scanning angles, degradation of side lobe levels in antenna arrays, and compromised performance of adaptive nulling in radar, communication, and other systems [1, 2]. In the context of conformal antennas, numerous methods exist for the assessment and mitigation of mutual coupling effects [3-5].

---

[*] Corresponding Author: alireza.monajati@yahoo.com
Yadegar-e-Imam Khomeini (RAH) Shahre Rey Branch, Islamic Azad University, Tehran, Iran

http://dx.doi.org/10.47176/TMI.2022.152

For instance, [3] employs a method of moments to analyze mutual coupling between rectangular patches on a multilayer circular-cylindrical structure. In [4], an interpolation technique is utilized to address mutual coupling issues in a conformal microstrip array. The impact of mutual coupling on correlation is investigated for printed antennas on a cylindrical substrate in [5]. It is emphasized that, in practical applications, mutual coupling reduction often holds more significance than mutual coupling compensation.

Several methods for mutual coupling reduction in the planar case include optimizing antenna dimensions, grooving the dielectric [6], adding additional dielectric layers to cover the patch [7], using shorting pins to cancel out capacitive polarization currents [8], introducing parasitic conducting tape between two antennas [9, 10], or employing a dielectric with band-gap properties [11]. Furthermore, periodic structures like photonic band-gap (PBG) and defected ground structures (DGS) have gained popularity due to their versatile applications in antennas and microwave circuits [12].

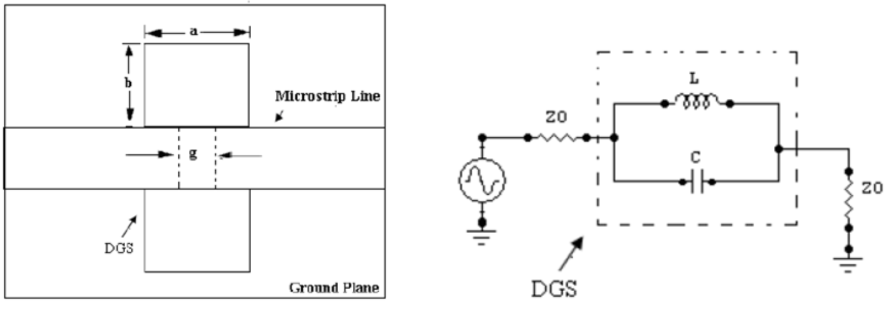
DGS is implemented by etching a defect into the ground plane of planar circuits and antennas. This defect disrupts the shield current distribution in the ground plane, altering transmission line characteristics such as capacitance and inductance. Consequently, DGS can furnish wide band-stop characteristics in specific frequency bands with just one or a small number of unit cells.

A prevalent drawback of microstrip antennas lies in the diminished radiation efficiency caused by the excitation of surface waves through the substrate layer [13]. This issue is further compounded by the disruption of the radiation pattern due to edge diffraction resulting from surface waves. In the context of arrays, surface waves not only contribute to these mentioned drawbacks but also exert a substantial influence on the mutual coupling between array elements. This impact is particularly disadvantageous in array designs where extremely low side lobe levels are crucial or in scanning array configurations, where impedance and pattern anomalies associated with scan blindness pose potential challenges for array designers [14].

To mitigate the effects of surface waves, the utilization of synthesized or micromachined substrates with a low effective dielectric constant is recommended. In recent years, the integration of Photonic Band Gap (PBG) structures has marked a significant breakthrough in enhancing the characteristics of microstrip antennas [13]. In this paper, we propose the incorporation of a Defected Ground Structure (DGS) unit within a three-element microstrip array. This DGS unit effectively suppresses surface waves, thereby reducing mutual coupling between three conformal microstrip rectangular patch antennas and resulting in very high isolation between array elements.

2. DESCRIPTION OF DGS CONFIGURATION AND FREQUENCY RESPONSE

In Fig. 1(a), the geometry of a dumb-bell shaped Defected Ground Structure (DGS) etched on the ground plane of a conventional 50-ohm microstrip transmission line is presented, where the dielectric constant is 4.3, and the thickness is 20 mil. The proposed DGS is represented by a parallel LC resonator in series with the transmission line, as depicted in Fig. 1(b). The equivalent circuit and the method for extracting the circuit parameters are extensively discussed [15]. The study demonstrates that the effective inductance of the microstrip increases with two connected square apertures etched on the ground plane, and the width of the connecting gap determines the shunt capacitance. Notably, both the inductance and capacitance levels can be independently controlled by adjusting the aperture area and the gap width, respectively.



(a) (b)

Fig. 1. (a) Microstrip transmission line with the DGS unit etched on the ground plane (a=b=8 mm, g=0.2 mm and w=0.955 mm). (b) Equivalent circuit of the DGS microstrip line proposed previously [15].

Utilizing CST Microwave Studio, the S-parameters of the defected ground microstrip line were computed, as presented in Fig. 2. The depicted results reveal that the DGS microstrip exhibits band-stop behavior, characterized by an attenuation pole at 5.3 GHz. The existence of a bandgap in such a structure has proven beneficial for enhancing the design characteristics of various microwave circuits. In this context, the Defected Ground Structure (DGS) is employed specifically to mitigate mutual coupling between elements in a microstrip antenna array.

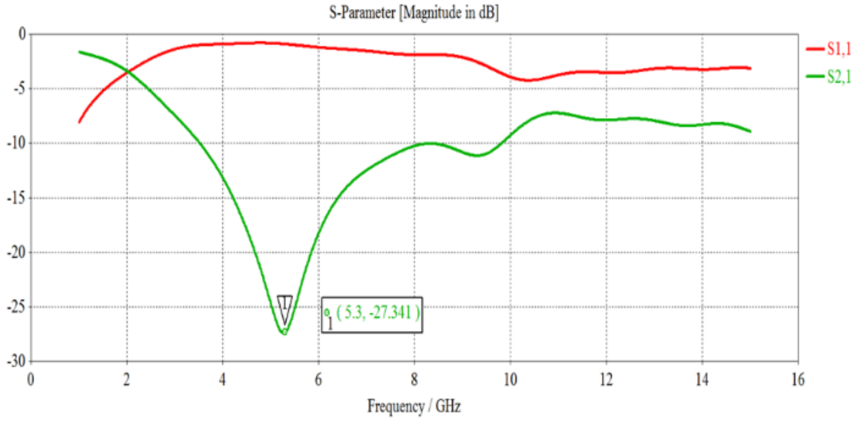


Fig. 2. Full-wave simulated S-parameters of the defected ground microstrip line.

3. SINGLE ELEMENT ANTENNA STRUCTURE

The configuration of the rectangular patch antenna is depicted in Figure 3. The patch has been meticulously modeled using CST Microwave Studio, and its dimensions have been fine-tuned to achieve resonance at 5.3 GHz. The conclusive dimensions of the entire microstrip patch are detailed in Table 1. Figure 4 illustrates the return loss of the patch element antenna. Evidently, the antenna resonates at 5.3 GHz, exhibiting a return loss of less than -10 dB within a bandwidth of 44 MHz.

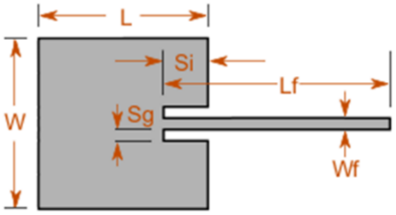


Fig. 3. The microstrip antenna dimensions when exposed to no curvature.

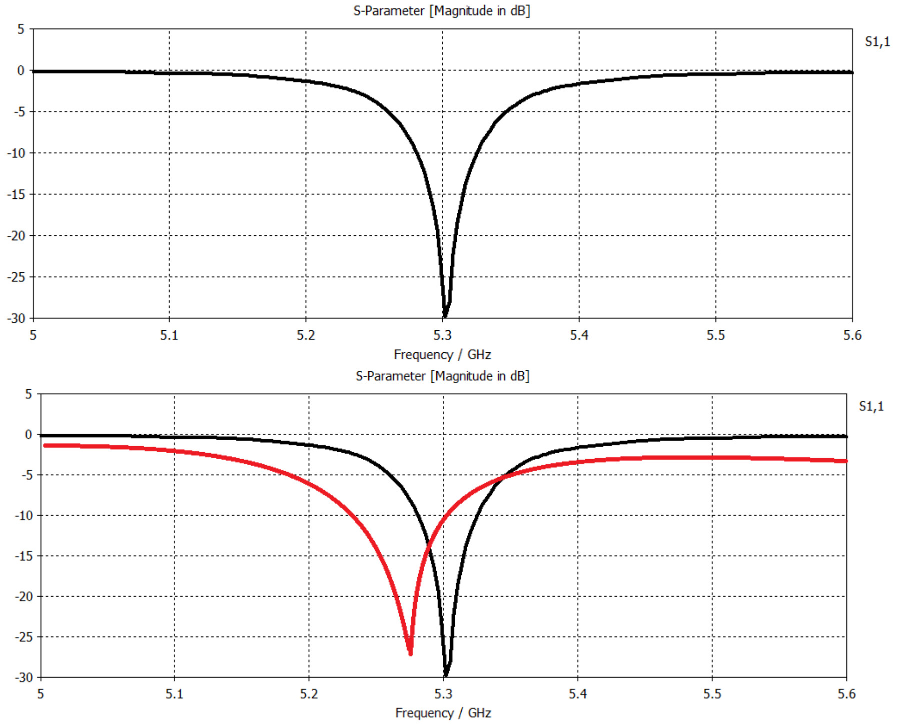


Fig. 4. Full-wave simulated Return-loss of the single microstrip antenna.

Table 1. Antenna Dimensions in mm

Parameters	**W**	**L**	**Si**	**Sg**	**Lf**	**Wf**	**Substrate Height**
Value	17.37	13.395	5.5	0.35	15.65	0.955	0.5

4. THE PROPOSED CONFORMAL ANTENNA ARRAY STRUCTURE

Three patch elements were evenly distributed on a cylindrical substrate. The substrate, used for modeling, has a thickness of 20 mil, with a dielectric constant of $\varepsilon r = 4.3$. The conductive material in the model is composed of 0.07 mm thick copper. The radius of the cylinder is set to be approximately one-quarter wavelength, and the height is specified as H = 30 mm. Within the cylinder, a continuous ground plane made of 0.07 mm thick copper is present. Figure 5 displays the model of the antenna array as represented in the simulation software.

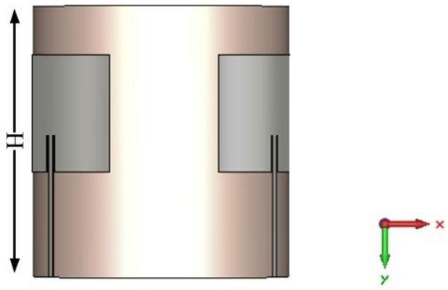


Fig. 5. A 2-D view of the modeled 3-element array.

5. THE PERFORMANCE EVALUATION

The cylindrical structure depicted in Figure 5 has been simulated using a commercially available finite element package, CST Microwave Studio. Various cylinders with radii of 14.15 mm were analyzed, while keeping the remaining antenna parameters constant. The simulation results, specifically the return loss of port 1 of the array and the coupling among the antenna elements, are presented in Figure 6. It is evident from Figure 6 that the coupling between elements for a 14.15 mm radius cylinder is approximately -40 dB at the resonant frequency.

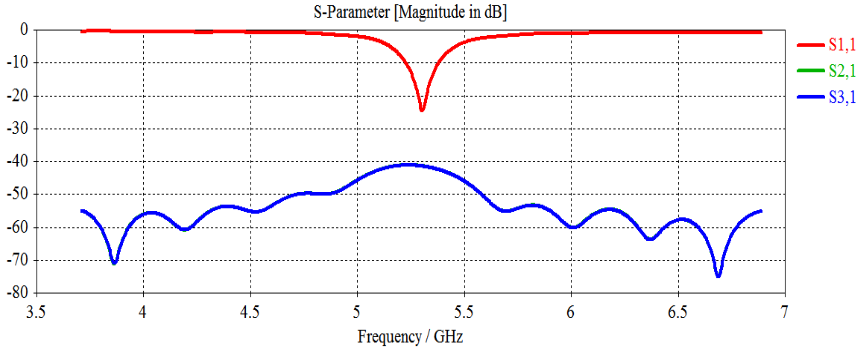
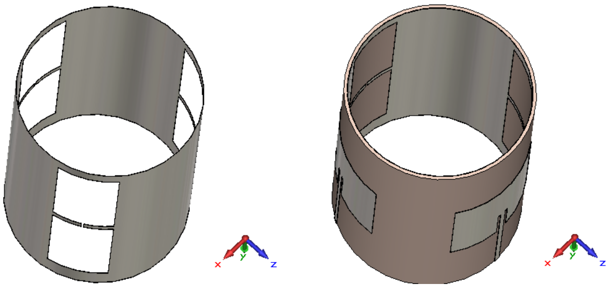


Fig. 6. Simulated coupling of the 3-element array conformed on cylinders with radii of 14.15 mm.

In the next step, DGS is used to mutual coupling reduction of a three-element microstrip antenna array.



(a) (b)

Fig. 7. A 3-D view of the (a) ground structure (b) modeled 3-element array.

The simulated S11, S21, and S31 parameters are illustrated in Fig. 8. The inclusion of the dumb-bell shaped Defected Ground Structure (DGS) etched on the ground plane results in a notable reduction in the S21 parameter, decreasing from -40 dB to -52.5 dB at the corresponding resonant frequency. This equates to a mutual coupling reduction of 12.5 dB. Similarly, the S31 parameter is reduced from -40 dB to -55.16 dB at the corresponding resonant frequency, yielding a substantial 15.16 dB reduction in mutual coupling across the antenna bandwidth.

Table 2. Antenna dimensions in mm.

Parameters	**a**	**b**	**g**	**w**
Value	10	14.5	0.2	0.955

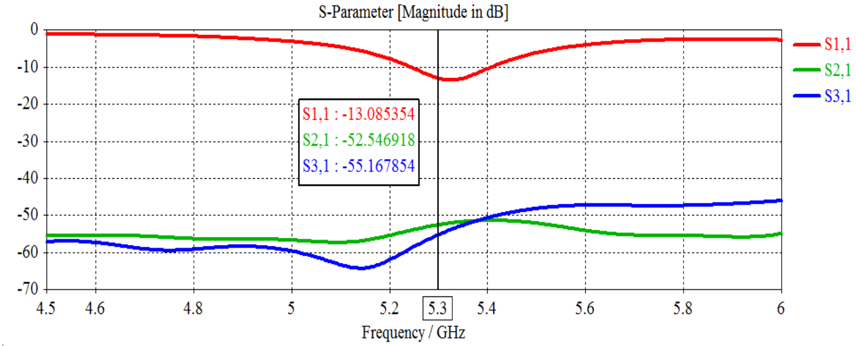


Fig. 8. Simulated coupling of the 3-element array conformed on cylinders with radii of 14.15 mm with DGS.

The surface waves of the antennas, both with and without the Defected Ground Structure (DGS), are depicted in Fig. 9. A clear comparison illustrates that the DGS structure effectively suppresses the mutual coupling between the three patches. Importantly, the introduction of the DGS structure does not adversely impact the radiation patterns of the antenna, as evident in Fig. 10. The radiation patterns exhibit no significant distortion, reaffirming the advantageous impact of the DGS structure on mutual coupling without compromising the antenna's radiation characteristics.

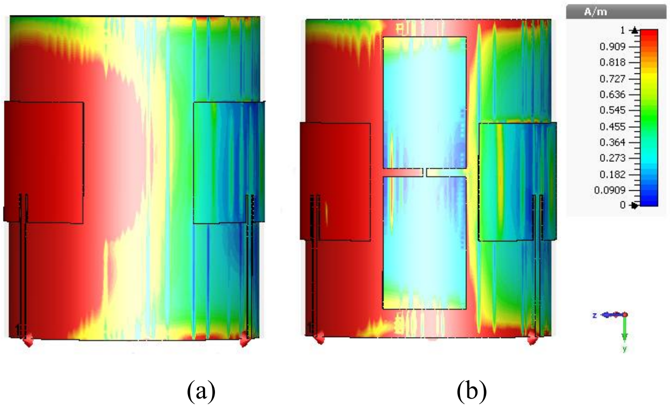


Fig. 9. The surface wave distributions of the conformal antenna (a) without DGS (b) with DGS.

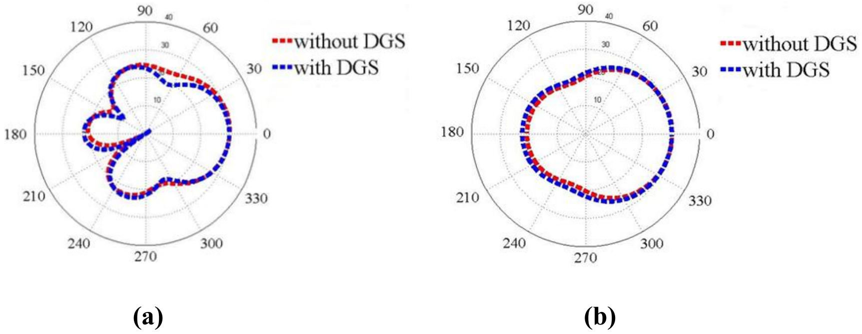


Fig. 10. Simulated (a) E-plane and (b) H-plane radiation patterns at the resonant frequency. The resonant frequency of the patch is 5.3 GHz

6. CONCLUSION

This paper introduces a novel approach to mitigate mutual coupling between three conformal microstrip patch antennas through the incorporation of a dumb-bell shaped defect on the ground plane. Simulated results demonstrate a notable 15 dB reduction in mutual coupling within the impedance bandwidth. The defected ground structure effectively suppresses surface waves, resulting in significantly reduced mutual coupling among the conformal patches. This DGS structure proves to be valuable for mutual coupling reduction in planar or conformal antenna arrays.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

Acknowledgments

We would like to express our gratitude to all individuals who contributed to this project.

Declaration of Interest

The authors declare that they have no competing interests.

Funding

This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

REFERENCES

[1] Pozar, D., & Schaubert, D. (1984). Analysis of an infinite array of rectangular microstrip patches with idealized probe feeds. IEEE Transactions on Antennas and Propagation, 32(10), 1101-1107. https://doi.org/10.1109/TAP.1984.1143211

[2] Pozar, D., & Schaubert, D. (1984). Scan blindness in infinite phased arrays of printed dipoles. IEEE Transactions on Antennas and Propagation, 32(6), 602-610. https://doi.org/10.1109/TAP.1984.1143375

[3] Matekovits, L., Dassano, G., & Vecchi, G. (2017). Mutual Coupling Reduction Between Implanted Microstrip Antennas on a Cylindrical Bio-Metallic Ground Plane. IEEE Access, 5, 8804-8811. https://doi.org/10.1109/ACCESS.2017.2703872

[4] Nadeem, I., & Choi, D. Y. (2019). Study on Mutual Coupling Reduction Technique for MIMO Antennas. IEEE Access, 7, 563-586. https://doi.org/10.1109/ACCESS.2018.2885558

[5] Mishra, N. K., Yadav, R. N., Abdelgawad, A., & Fouda, A. (2022). Mutual coupling reduction between the cylindrical dielectric resonator antenna using split ring resonator based structure. AEU - International Journal of Electronics and Communications, 154, 154305. https://doi.org/10.1016/j.aeue.2022.154305

[6] Fritz-Andrade, E., Arias-Vergara, T., Guzman-Quirós, R., González-Ovejero, D., & Martínez-Viviente, F. L. (2020). Characteristic mode analysis applied to reduce the mutual coupling of a four-element patch MIMO antenna using a defected ground structure. IET Microwaves, Antennas & Propagation, 14(2), 215-226.

https://doi.org/10.1049/iet-map.2019.0570

[7] Mandal, S., & Ghosh, C. K. (2021). Low Mutual Coupling of Microstrip Antenna Array Integrated with Dollar Shaped Resonator. Wireless Personal Communications, 119(1), 777-789. https://doi.org/10.1007/s11277-021-08237-1

[8] Ghimire, J., Choi, K.-W., & Choi, D.-Y. (2019). Bandwidth Enhancement and Mutual Coupling Reduction Using a Notch and a Parasitic Structure in a UWB-MIMO Antenna. International Journal of Antennas and Propagation, 2019(1), 8945386. https://doi.org/10.1155/2019/8945386

[9] Mishra, M., Abdelgawad, A., Fouda, A., & Yadav, R. N. (2022). New Design Approach for Mutual Coupling Reduction in Two-Port Compact Antenna Array for W-LAN MIMO Applications. In 2022 3rd URSI Atlantic and Asia Pacific Radio Science Meeting (AT-AP-RASC) (pp. 1-4). https://doi.org/10.23919/AT-AP-RASC54737.2022.9814375

[10] Yang, F. m., Yin, Y. z., Li, Q., Zhao, G. j., & Xu, Y. (2019). Coupling Reduction for a Wideband Circularly Polarized Conformal Array Antenna With a Single-Negative Structure. IEEE Antennas and Wireless Propagation Letters, 18(5), 991-995. https://doi.org/10.1109/LAWP.2019.2907134

[11] Satam, V., & Nema, S. (2018). Two Element Compact UWB Diversity Antenna with Combination of DGS and Parasitic Elements. Wireless Personal Communications, 98(3), 2901-2911. https://doi.org/10.1007/s11277-017-5006-5

[12] Mohamadzade, B., Khaleghi, A., Amiri, I. S., & Mokayef, M. (2020). Mutual coupling reduction in microstrip array antenna by employing cut side patches and EBG structures. Progress In Electromagnetics Research M, 89, 179-187. https://doi.org/10.2528/PIERM19100703

[13] Niu, Z., Luo, Q., Gui, G., & Gao, X. (2019). A novel defect ground structure for decoupling closely spaced E-plane microstrip antenna array. International Journal of Microwave and Wireless Technologies, 11(10), 1069-1074. https://doi.org/10.1017/S1759078719000801

[14] Beiranvand, E., Afsahy, M., & Sharbati, V. (2017). Reduction of the mutual coupling in patch antenna arrays based on EBG by using a planar frequency-selective surface structure. International Journal of Microwave and Wireless Technologies, 9(2), 349-355. https://doi.org/10.1017/S1759078715001440

[15] Ahn, D., Park, J.-S., Kim, C.-S., Qian, Y., & Itoh, T. (2001). A design of the low-pass filter using the novel microstrip defected ground structure. IEEE Transactions on Microwave Theory and Techniques, 49(1), 86-93. https://doi.org/10.1109/22.899965