A Miniaturized Polarization Independent Frequency Selective Surface with Stepped Profile for Shielding Applications

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Abstract **─** In this paper, a miniaturized Frequency Selective Surface (FSS) with band-stop characteristics is presented for shielding applications. The FSS is designed to notch at 3.5 GHz frequency in the WiMAX band. The design is composed of a circular metallic patch with identical stepped profile printed on both sides of a low cost FR-4 laminate. The design provides an attenuation of 43 dB at desired resonant frequency. The FSS geometry makes it independent of polarization and it offers stable transmission response. Oblique angle variations don't affect the unit cell performance, for transverse electric and transverse magnetic modes of polarization. The FSS unit cell is compact with the dimensions of 25×25 mm^2. The simulated and measured results show good agreement for the proposed design.

Index Terms **─** Frequency Selective Surface (FSS), periodic structure, stepped profile, transverse electric, transverse magnetic, WiMAX band.

I. INTRODUCTION

The FSSs are periodically arranged metallic patches or slots in two or three dimensional fashion. They have comprehensive attraction for their microwave and optical applications including Radar Cross Section (RCS) reduction [1-3], antenna radomes, dichroic subreflectors, electromagnetic absorbers, wireless security, indoor wireless propagation, electromagnetic interference (EMI) reduction and many others [1, 4-9]. They are used as EBG structures and High Impedance Surfaces (HISs) to improve the antenna gain, directivity and bandwidth [10-13].

In recent reported literature, various researches on FSSs for band stop and electromagnetic shielding applications [14-19] are investigated. FSSs with band-stop characteristics for WLAN applications are reported in [5, 10]. Reconfigurable frequency selective surfaces for band-reject applications are studied in [20]. A tunable FSS for electromagnetic building architecture is stated in [21]. An FSS for gain enhancement of microstrip triangular slot antenna for X-band is presented in [12]. Polarization independent FSS used for RCS reduction is reported in [3].

In this research, a miniaturized FSS with shielding characteristics is proposed. The FSS suppresses interference at 3.5 GHz frequency in WiMAX band. The FSS unit cell consists of a circular patch of metal having symmetrical staircase profile realized on both sides of an FR-4 substrate. The FSS shows an attenuation of 43 dB at the desired frequency. Moreover, it shows stable and identical transmission frequency characteristics over oblique angle variations for Transverse Electric (TE) and Transverse Magnetic (TM) polarizations of the incident wave.

Rest of the paper is arranged as follows: in Section II the design description of proposed FSS is presented. The simulated results and discussions are presented in Section III. The measurement fixture and measurement results are discussed in Section IV. Finally, Section V summarizes and concludes the paper.

II. FSS UNIT CELL DESIGN

The FSS unit cell consists of a circular metallic patch with a staircase profile at the middle. The diameter of circular metallic patch is $L_1 + 2P$. FSS structure is designed and fabricated on both sides of a low cost FR-4 laminate having thickness of 1.6 mm, a relative permittivity of $\varepsilon_r = 4.4$ and dielectric loss tangent, tan δ,

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of 0.02. Moreover, the FSS design has overall dimensions of L × W = 25 × 25 mm^2. The FSS unit cell is shown in Fig. 1.

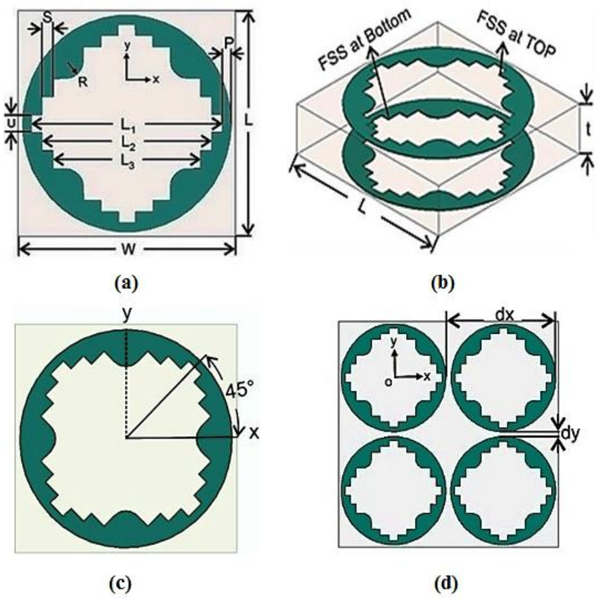

Fig. 1. FSS unit cell structure: (a) top view, (b) perspective view, (c) unit cell rotation at 45^o, and (d) A 2 × 2 unit cell array.

The stepped profile is designed by eliminating rectangular stubs from solid interior of circular patch. These stubs are variable in lengths but each has width of 2 mm. The step size of this staircase profile has length S = 1.25 mm and U = 2 mm height. The horizontal rectangular stub at center of the patch along x-axis has dimensions L_1 × U = 22 mm × 2 mm. Moreover, second and third stubs below the stub at center of patch have dimensions L_2 × U = 19.5 mm × 2 mm and L_3 × U = 17 mm × 2 mm respectively. The upper half of staircase profile along x-axis is a mirror replica of stubs below the central horizontal stub. In order to have symmetry in the unit cell along y-axis the same geometry is replicated.

It was realized from the simulations that the staircase profile works to obtain maximum attenuation at the frequency of interest. It provides angular stability in the frequency transmission response of the proposed FSS structure. Moreover, a bevelled notch with a radius of R = 2 mm as shown in Fig. 1 (a), gives an additional attenuation of 4 dB at the notching frequency. All other surface edges in unit cell structure have no effect on its performance. The design can bear up to 1.5 mm variation in the edges. A metallization of P = 1 mm on sides of the unit cell completes the circular patch. However, variation in the radius of the circular patch results in shift in the frequency transmission curve. Furthermore, the same FSS structure on the flip side of the substrate provides compactness and miniaturization in the unit cell size, along with the stability in the frequency response over incidence angle variations. The FSS unit cell is constructed and optimized in commercially available full-wave software HFSS®.

III. RESULTS AND DISCUSSIOS

In this section, the results of the proposed FSS are presented. Figure 2 shows the scattering characteristics of the FSS unit cell at normal incidence, for both TE and TM modes of polarization. The design provides good transmission loss at the frequency of interest, as shown in Fig. 2. It may be observed that the FSS offers stable and identical transmission response for both the TE and TM polarization modes at normal incidence (0^o), due to circular geometry of proposed FSS and symmetry in structure along x-axis and y-axis.

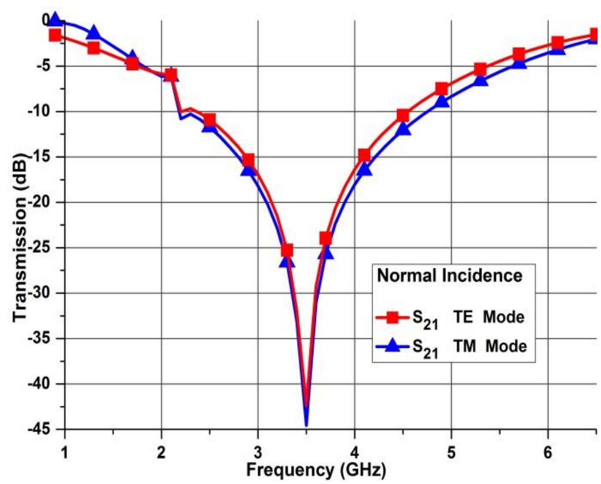

Fig. 2. Transmission behaviour of the FSS at normal incidence.

The magnitude of transmission coefficient (S_{21}) for TE mode at different incident angles is shown in Fig. 3. The angle of incidence of the incoming waves is changed from 0 to 60 degrees at regular intervals of 30 degrees. The FSS has stable frequency transmission characteristics irrespective of oblique angles variations.

Furthermore, the transmission characteristics of the FSS for TM mode at various incidences are plotted in Fig. 4. The results for TM mode are stable and identical to TE mode. It may be observed from the Figs. 3 and 4 that the FSS at -20 dB provides 1 GHz bandwidth of stopband, sufficient enough to suppress communication in the desired band. The rejection bandwidth increases as the oblique incident angle is varied. However, the bandwidth varies within the acceptable limits over angle variations, for both the TE and TM wave modes.

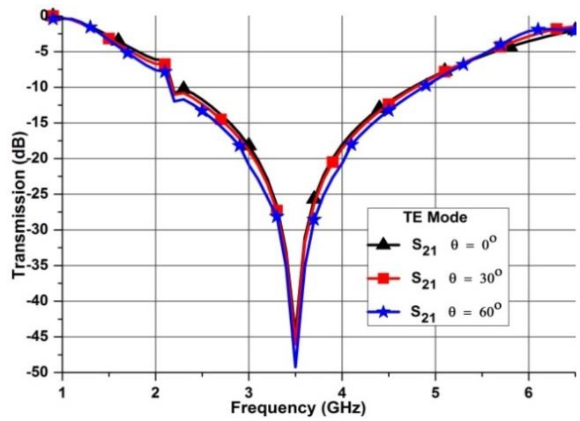

Fig. 3. Magnitude of transmission coefficient for TE mode of polarization at various incident angles.

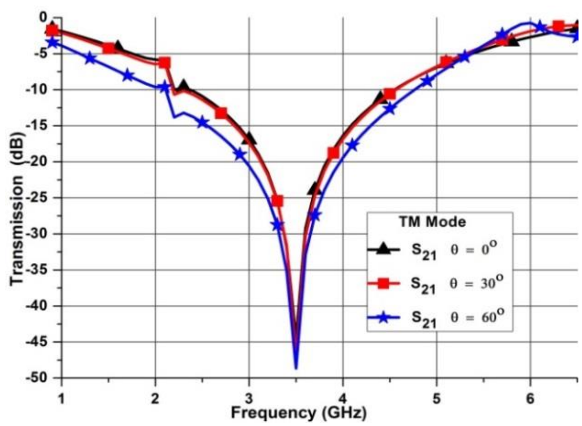

Fig. 4. S_{21} plot for TM mode over oblique angle variations.

A. Unit cell rotation at 45º

Furthermore, the FSS structure is rotated at an angle of 45º, to evaluate its performance as shown in Fig. 1 (c). The circular geometry of the FSS reduces the sensitivity to oblique incidences and makes it independent to polarization. The frequency transmission plots of the FSS when it is exposed to horizontal and vertical polarizations are shown in Figs. 5 and 6 respectively. It has been observed that the FSS shows stable response for both TE and TM modes. However, little deviations are observed in the resonant frequency with respect to the angle variations but these can be neglected at higher frequencies.

B. Dielectric thickness analysis

Thickness of the dielectric plays an important role in FSS characteristics. Variation in dielectric thickness results in shifting of the resonant frequency. The transmission characteristics as a function of dielectric thickness are plotted in Fig. 7. However, it is evident from the Fig. 7 that variations in the resonant frequency with respect to dielectric thickness are within the tolerable limits for the proposed design.

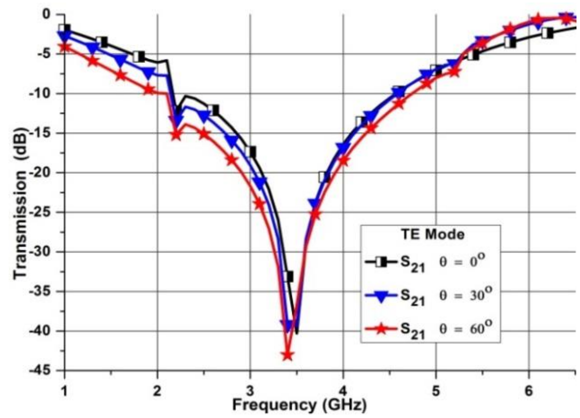

Fig. 5. Transmission response of FSS element rotated at 45º for TE mode.

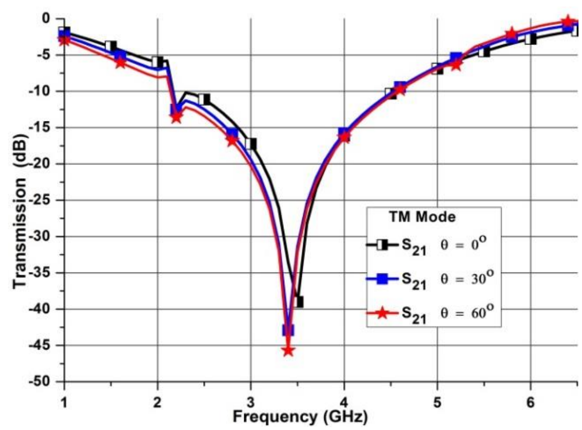

Fig. 6. Transmission characteristics of FSS rotated at 45º for TM mode over different oblique angles.

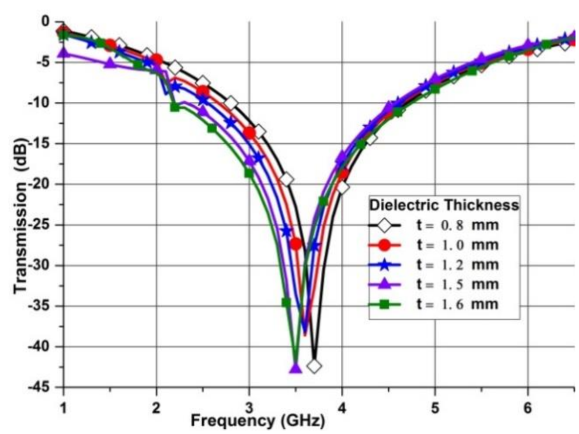

Fig. 7. Resonat frequency variations with respect to dielectric thickness.

IV. MEASUREMENT SETUP

To verify the designed FSS structure, a prototype is fabricated using the standard etching process. The FSS is realized on a lossy FR-4 substrate of 1.6 mm thickness. The fabricated FSS panel has dimensions of 256×256 mm^2. Moreover, it contains 10×10 FSS elements as depicted in Fig. 8. The measurements are carried out through standard free-space measurement method as shown in Fig. 9. The measurement setup consists of a pair of high gain horn antennas connected to Rohde & Schwarz FSH8 vector network analyzer (VNA) as shown in Fig. 10. The transmitting and receiving antennas are equally spaced from the FSS panel. The measured transmission responses of the fabricated prototype for both TE and TM modes are presented in Figs. 11 and 12 respectively. It is evident that the measured transmission response validates the simulations. However, some variations in the measured results are due to the lossy dielectric material used and measurement limitations.

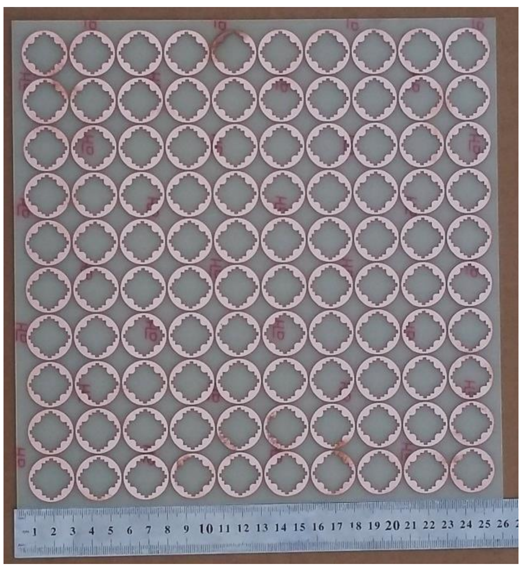

Fig. 8. Photograph of the fabricated FSS prototype.

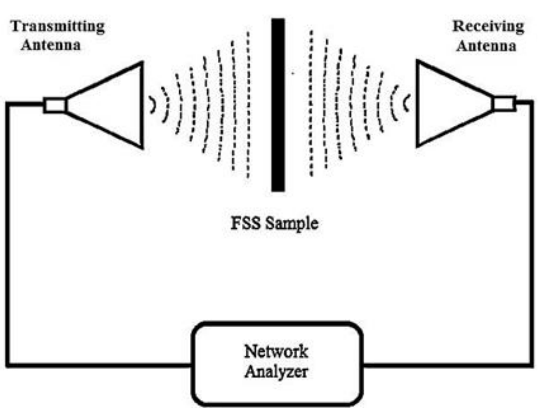

Fig. 9. FSS free-space measurement method.

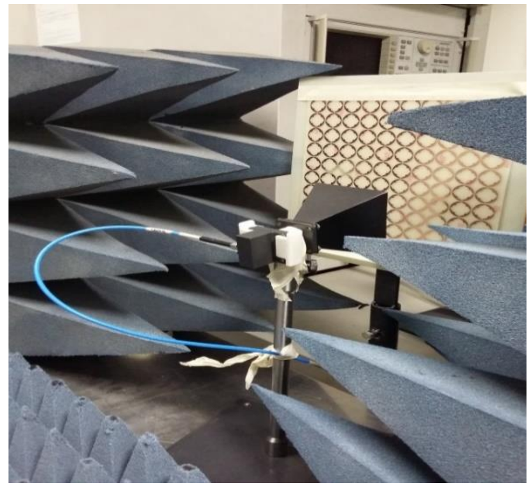

Fig. 10. Photo of measurement setup.

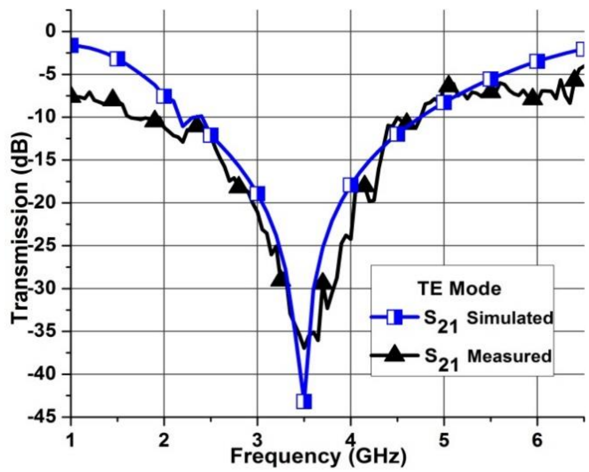

Fig. 11. Comparison of simulated and measured transmission coefficient for TE mode.

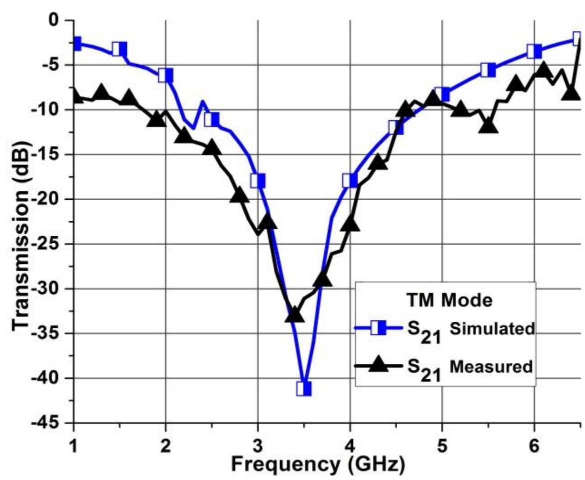

Fig. 12. Measured and simulated transmission for TM mode.

V. CONCLUSION

In this research work, a miniaturized polarization independent FSS with band-stop characteristics is proposed. The FSS is designed to notch at 3.5 GHz frequency and it offers shielding effectiveness of at least 43 dB. FSS design has a circular patch with staircase profile, realized on both sides of laminate. The staircase profile in the unit cell provides miniaturization and stability in response. Moreover, the FSS shows identical frequency transmission characteristics for TE and TM modes, making it suitable for angular as well as polarization independent operation. FSS unit cell has compact size and is scalable at other frequencies. More importantly the proposed FSS is a virtuous candidate to suppress communication in the WiMAX band.

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REFERENCES

[1] B. A. Munk, *Frequency Selective Surfaces: Theory and Design*. John Wiley & Sons, 2005.

[2] H. Zhou, L. Yang, S. Qu, K. Wang, J. Wang, H. Ma, and Z. Xu, "Experimental demonstration of an absorptive/transmissive FSS with magnetic material," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 114-117, 2014.

[3] A. Edalati and K. Sarabandi, "Wideband, wide angle, polarization independent RCS reduction using nonabsorptive miniaturized-element frequency selective surfaces," *IEEE Transactions on Antennas and Propagation*, vol. 62, pp. 747-754, 2014.

[4] X.-C. Zhu, W. Hong, K. Wu, H.-J. Tang, Z.-C. Hao, J.-X. Chen, H.-X. Zhou, and H. Zhou, "Design of a bandwidth-enhanced polarization rotating Frequency Selective Surface," *IEEE Transactions on Antennas and Propagation*, vol. 62, pp. 940-944, 2014.

[5] R. Natarajan, M. Kanagasabai, S. Baisakhiya, R. Sivasamy, S. Palaniswamy, and J. K. Pakkathillam, "A compact frequency selective surface with stable response for WLAN applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 718-720, 2013.

[6] I. S. Syed, Y. Ranga, L. Matekovits, K. P. Esselle, and S. G. Hay, "A single-layer frequency-selective surface for ultrawideband electromagnetic shielding," *IEEE Transactions on Electromagnetic Compatibility*, vol. 56, pp. 1404-1411, 2014.

[7] S. Cimen, "Novel closely spaced planar dual-band frequency-selective surface," *IET Microwaves, Antennas & Propagation*, vol. 7, pp. 894-899, 2013.

[8] L. Meng and N. Behdad, "Frequency selective surfaces for pulsed high-power microwave applications," *IEEE Transactions on Antennas and Propagation*, vol. 61, pp. 677-687, 2013.

[9] A. K. Rashid, S. Zhongxiang, and S. Aditya, "Wideband microwave absorber based on a two-dimensional periodic array of microstrip lines," *IEEE Transactions on Antennas and Propagation*, vol. 58, pp. 3913-3922, 2010.

[10] I. G. Lee and I. P. Hong, "3D frequency selective surface for stable angle of incidence," *Electronic Letters*, vol. 50, pp. 423-424, 2014.

[11] Y. Mingbao, Q. Shaobo, W. Jiafu, Z. Jieqiu, Z. Hang, C. Hongya, and Z. Lin, "A miniaturized dual-band FSS with stable resonance frequencies of 2.4 GHz/5 GHz for WLAN applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 895-898, 2014.

[12] E. Moharamzadeh and A. M. Javan, "Triple-band frequency selective surfaces to enhance gain of X-band triangle slot antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 1145-1148, 2013.

[13] C.-N. Chiu and W.-Y. Wang, "A dual-frequency miniaturized element FSS with closely located resonances," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 163-165, 2013.

[14] C. J. Davenport and J. M. Rigelsford, "Design of comb reflection frequency selective surface for interference reduction in corridors of buildings," *Electronic Letters*, vol. 49, pp. 1478-1479, 2013.

[15] Y. Shi, W. Tang, W. Zhuang, and C. Wang, "Miniaturised frequency selective surface based on 2.5-dimensional closed loop," *Electronic Letters*, vol. 50, pp. 1656-1658, 2014.

[16] U. Rafique, S. A. Ali, M. T. Afzal, and M. Abdin, "Bandstop filter design for GSM shielding using frequency selective surfaces," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 2, pp. 846-850, 2012.

[17] A. K. Rashid and S. Zhongxiang, "A novel band-reject frequency selective surface with pseudo-elliptic response," *IEEE Transactions on Antennas and Propagation*, vol. 58, pp. 1220-1226, 2010.

[18] B. Sanz-Izquierdo and E. A. Parker, "Dual polarized reconfigurable frequency selective surfaces," *IEEE Transactions on Antennas and Propagation*, vol. 62, pp. 764-771, 2014.

[19] B. Li and Z. Shen, "Miniaturized bandstop frequency-selective structure using stepped-impedance resonators," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 1112-1115, 2012.

[20] B. Sanz-Izquierdo and E. A. Parker, "Dual polarized reconfigurable frequency selective surfaces," *IEEE Transactions on Antennas and Propagation*, vol. 62, pp. 764-771, 2014.

[21] K. L. Ford, J. Roberts, S. Zhou, G. Fong, and J.

Rigelsford, "Reconfigurable frequency selective surface for use in secure electromagnetic buildings," *Electronic Letters*, vol. 49, pp. 861-863, 2013.

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