A polygonal open-loop resonator compact bandpass filter for Bluetooth and WLAN applications

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Abstract. In this paper, a new bandpass filter is designed using two open-loop resonators with polygonal forms. The use of polygonal forms leads to compact size and broad bandwidth behavior. The overall filter dimensions are 8×16 mm2, which correspond to 0.4λg × 0.2λg using a substrate with Rogers Ro 3010 with a relative permittivity of 10.2 and a thickness of 1.5 mm. The resulting filter exhibits enhanced passband behavior with two transmission zeros. The resulting passband has a centre frequency of 2.40 GHz, and a bandwidth of 230 MHz and fractional bandwidth (FBW) of 10%, with return loss of about –26 dB and insertion loss equal to -0.8 dB. The locations of the two transmission zeros are at 2.176 GHz and 2.638 GHz, which means that there is a sharp cut before and beyond the passband. The simulation and performance evaluation of the proposed filter were carried out using Microwave Studio Suite (MWS) Computer Simulation Technology (CST). The resulting performance of the proposed filter makes it very desirable for Bluetooth and WLAN applications (IEEE 802.11n).

Keywords - open-loop-resonator, microstrip bandpass filter, multiband BPF

1. Introduction

The tremendous development that has occurred in modern wireless equipment has stimulated design of low-profile compact microstrip filters, especially in terms of the design of bandpass filters. This is because of overcrowding in the frequencies allocated to these uses due to the proliferation of applications. In these types of filters, several factors play an essential role in the design process. Compact size, low cost, and high performance are generally considered the most important factors [1], however, as these are indispensable in terms of enhancing performance and facilitating the process of device manufacture. These requirements thus encourage microwave system designers to investigate different configurations of resonators. The real challenge that the researchers now face is thus obtaining bandpass filters that are characterised by their excellent passbands, large stop bands, low profiles, and ease of fabrication. Stepped impedance parallel lines have been used in designing BPFs, as introduced in [2] to [4], and several forms and configurations have been investigated in the design and construction of resonators for the bandpass filter. Some of these resonators depend on Euclidean figures,

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as in [5] to [7], while others make use of fractal shapes as in [8] to [10]. Some researchers have also adopted the idea of etching slots on the top, bottom, or both layer(s) of the planar structures, and these slots can take various forms [11].

Alongside the use of slots, a substrate integrated waveguide is frequently included to promote high efficiency and low leakage loss, as in [12] to [14]. However, the open-loop resonator is the most widely used in BPF design. Researchers tend to prefer this type of resonator because of its capability to promote size reduction and the flexibility of its coupling amount, which depends on the coupling sides [15].

In [16], an open-loop BPF based on adding a series of resonant circuits to the open ends of the resonator was investigated. A dual-band at 2.4 GHz and 5.8 GHz was thus obtained. In [17], five open-loop resonators with two parallel transmission lines were used to develop good isolation between the two passbands, while in [18], a cross-coupled trisection bandpass filter based on open-loop resonators was been designed and simulated.

An outer-folding open-loop resonator with triple mode stub-loaded resonators was proposed in [19], and in [20], two slotted open-loop resonators with a closed end resulted in an elliptical frequency response. Meanwhile, in [21], an open-loop triangular ring resonator was loaded with a stub, and a multilayer technology was reported in [22], whereby four spiral resonators were placed on two stacked layers to achieve a reduced size bandpass filter.

2. The proposed filter design

In this paper, a new polygon open-loop resonator compact bandpass filter is presented. The resonator element consists of 11 segments of different lengths; these segments do not intersect with each other, as illustrated in Figure 1. The length of some of these segments can be increased without increasing the resonator area, which is an important feature in this design compared with the conventional open loop resonator. The proposed filter has double resonators, each occupying an area of 4.3×5.8 mm^2. The proposed filter structure is designed using a substrate with Rogers Ro 3010, with a relative permittivity of 10.2 and a thickness of 1.5 mm. The length of the resonators is equal to *lr,* which is given by

$$lr = x1+2x2+x3+x4+y1+y2+y3+yg1+yg2 \qquad (1)$$

where *x1, x2, x3, x4, y1, y2, y3, yg1, and yg2* are as labelled in Figure 1.

Consequently, the filter size can be expressed in terms of *lr* and the guided wavelength, λ_g as

$$\lambda_g = \frac{\lambda_\circ}{\sqrt{\varepsilon_{eff}}} \qquad (2)$$

where ε_{eff} is the effective dielectric constant. Considering that the proposed resonators here are of type $\lambda_g/4$ yields

$$\lambda_g = 4\ lr \qquad (3)$$

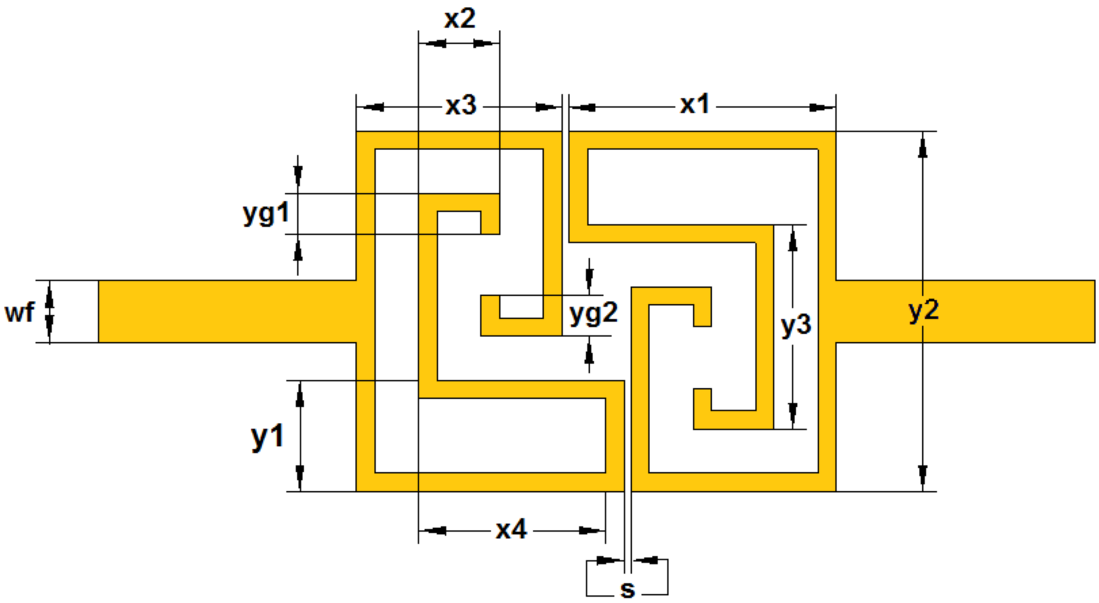


Figure 1. The polygon resonators for the proposed microstrip bandpass filter structure.

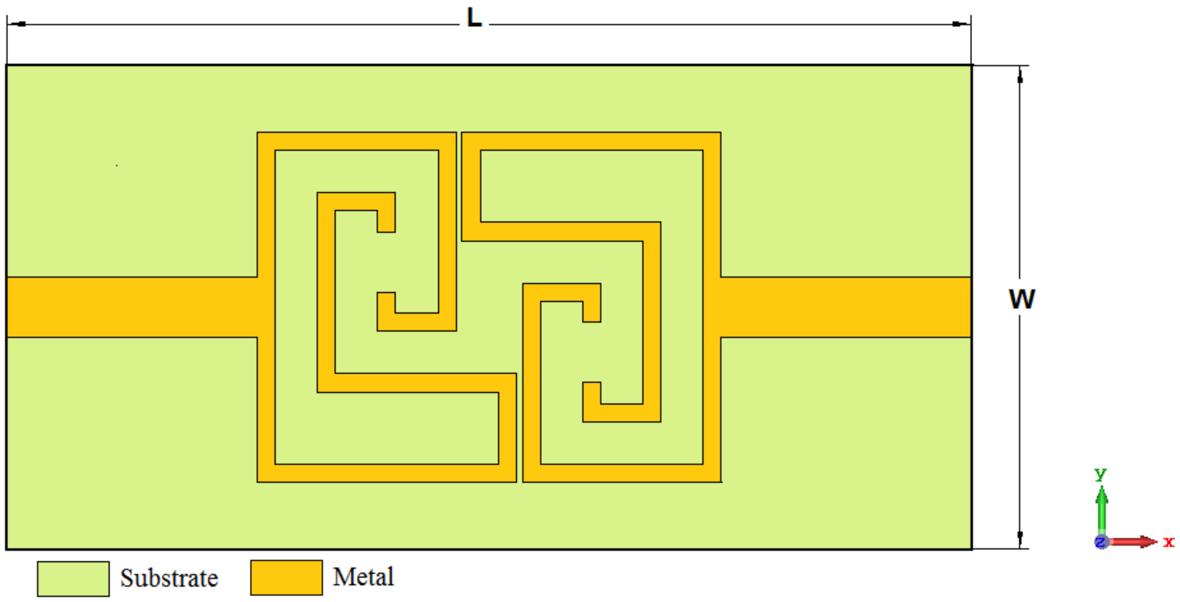
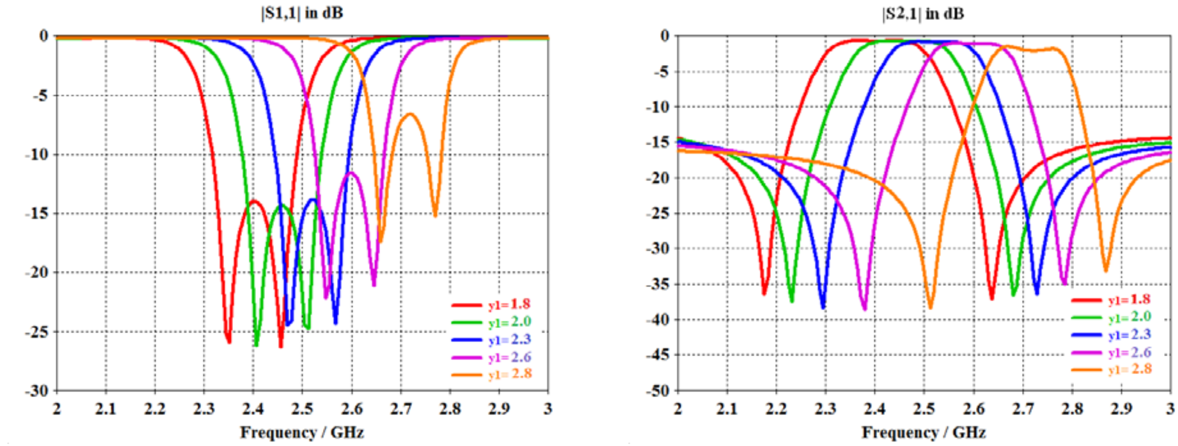


Figure 2. CST MWS model for the microstrip bandpass filter structure.

3. Performance evaluation

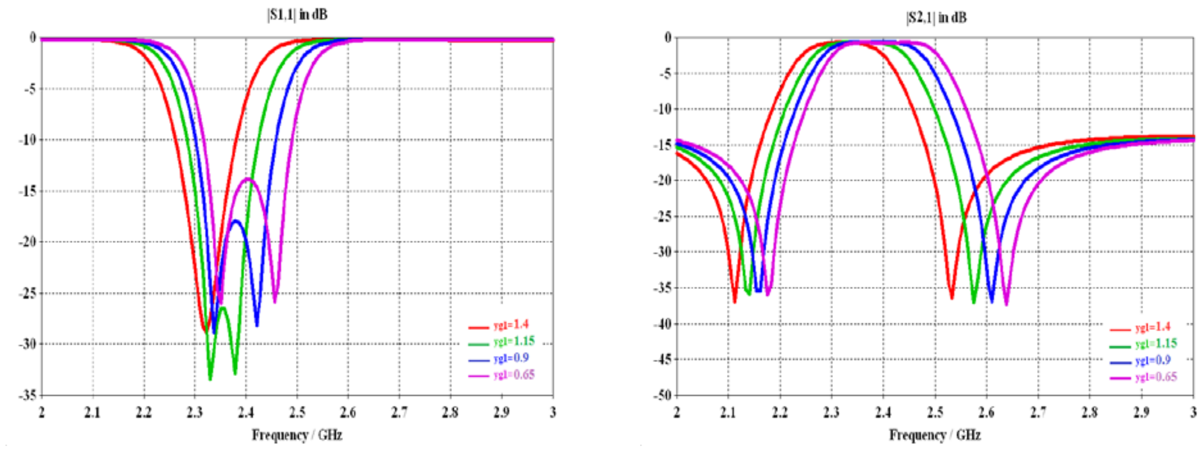
The Microwave Studio Suite of Computer Simulation Technology (CST) [23] was used to model and analyse the filter structures depicted in Figures 1 and 2. The CST simulator performs electromagnetic analysis using the finite-difference time-domain (FDTD). The effects of various parameters on filter performance are thus taken into consideration, and this is accomplished by means of parametric study of each parameter. All parameters are illustrated in Figure 1, and appropriate values for these parameters were chosen to make the proposed filter resonate at 2.40 GHz.

The investigation of the parameter *y1* is presented in Figure 3. The centre frequency can be moved forward by increasing this parameter; at the same time, the level of the input reflection coefficient (s11) would decrease, as shown in Figure 3a, and the position of lower transmission zero moves up more than that of the higher one. The level of insertion loss generally changes slightly, as shown in Figure 3b. At higher values of *y1*, the two transmission zeros tend to move closer to each other.



(a) (b)

Figure. 3. The simulated S-Parameter responses of the proposed filter to parameter *y1*: (a) input reflection coefficient (s11) and (b) insertion loss (s21).

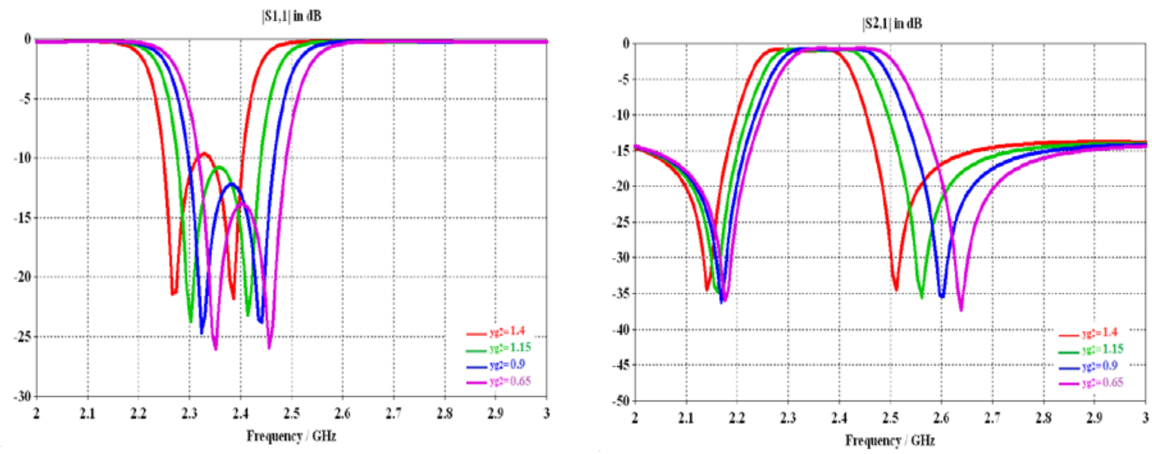


(a) (b)

Figure 4. The simulated S-Parameter responses of the proposed filter to parameter *yg1*: (a) input reflection coefficient (s11) and (b) insertion loss (s21).

The effect of parameter *yg1* can be monitored as seen in Figure 4. It is clear that decreasing the value of *yg1* does not affect the position of the centre frequency much, but that the level of s11 is considerably affected (decreased), as shown in Figure 4a. The locations of the transmission zeros are not affected much as compared with the case of varying *y1*, as illustrated in Figure 4b.

Figure 5 illustrates the effect of changing the parameter *yg2*. Note that the decrease in *yg2* value leads to an increase in the centre frequency, and, at the same time, the level of s11 is increased as shown in Figure 5a. In contrast to parameter *yg1*, a decrease in value of the *yg2* parameter has a diacritical effect on the location of the higher transmission zero, Tz2 (increased), while the location of the lower transmission zero, Tz1, does not respond much to this parameter, as shown in Figure 5b.

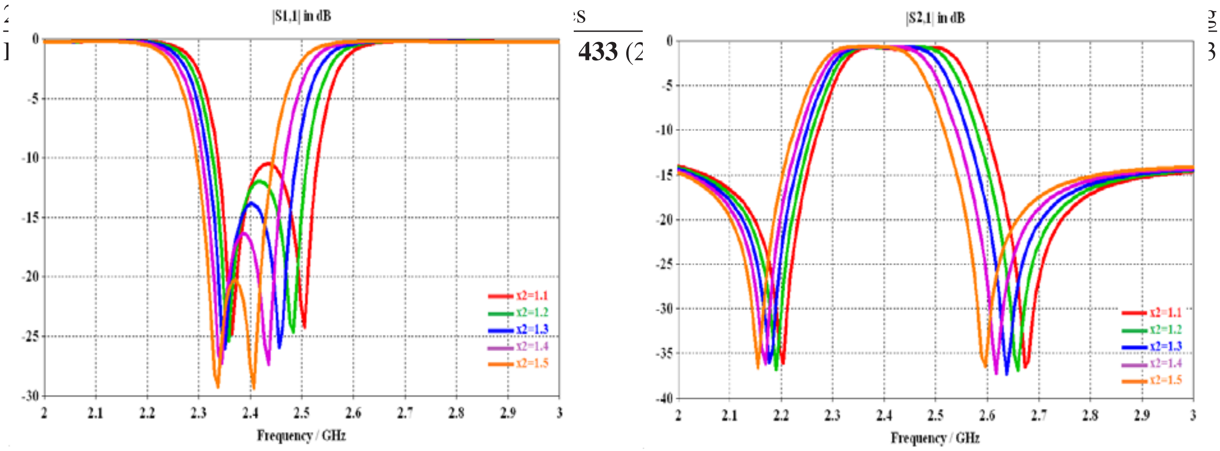


(b) (b)

Figure 5. The simulated S-Parameter responses of the proposed filter to parameter yg2: (a) input reflection coefficient (s11) and (b) insertion loss (s21).

Although parameters *yg1* and *yg2* represent the dimensions of the two folded ends of the resonator and have the same values and orientation, they have different impacts on the filter response. The interpretation of this is that this is due to the asymmetry of the resonator shape with respect to the feeding point, unlike conventional open-loop resonators. Therefore, the proposed filter in this paper possesses an extra advantage which offers the possibility of filter behaviour improvement.

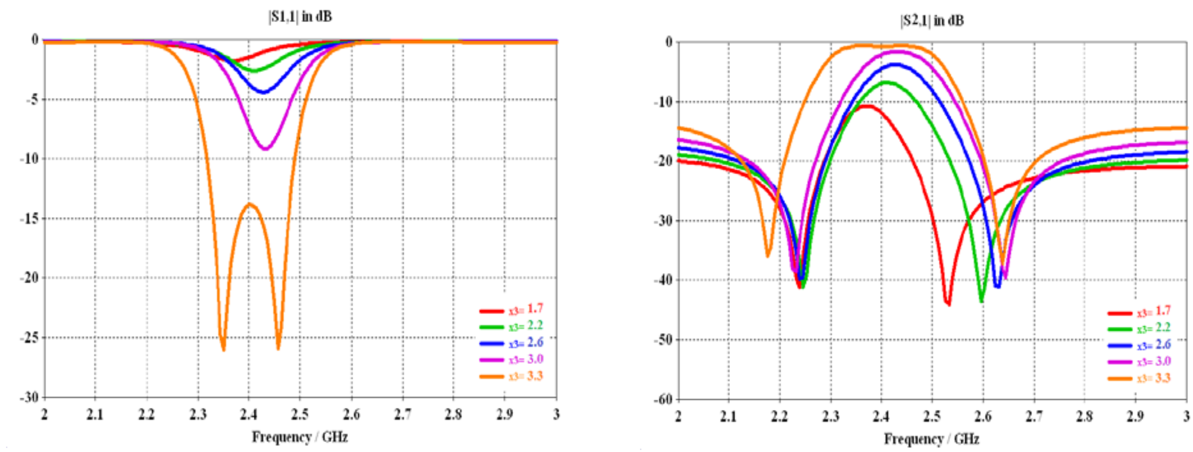
The *x2* parameter has a remarkable effect on filter performance in that the centre frequency increases as the value of *x2* decreases, as shown in Figure 6a. However, when *x2* value increases, this leads to the locations of transmission zeros moving down, especially in the case of the higher one, as noted in Figure 6b.



(a) (b)

Figure 6. The simulated S-Parameter responses of the proposed filter for parameter *x2*: (a) input reflection coefficient (s11) and (b) insertion loss (s21).

The final parameter to be taken into consideration is the *x3* parameter. The *x3* parameter has a clear influence on the performance of the proposed filter: when the value of this parameter is less than 3.3 mm, there is no salient response in s11, as shown in Figure 7a. The location of the Tz1 remains relatively constant, while the Tz2 moves as illustrated in Figure 7b.



(a) (b)

Figure 7. The simulated S-Parameter responses of the proposed filter for parameter *x3*: (a) input reflection coefficient (s11) and (b) insertion loss (s21).

As mentioned earlier, the proposed open-loop resonator has the important feature that it is characterized by the possibility of varying segments to any desired frequency lower than 2.4 GHz without increasing the area occupied by each resonator. The appropriate values of all parameters that affect the response are shown in Table 1.

Table 1: Summary of the dimensions of the proposed filter

Parameter	*x1*	*x2*	*x3*	*x4*	*y1*	*y2*	*y3*	*yg1*	*yg2*	*wf*	*s*	*L*	*W*
Value (mm)	4.3	1.3	3.3	3.3	1.8	5.8	3.3	0.65	0.65	1.0	0.10	16	8.0

Figure 8 demonstrates the final response of the proposed filter in terms of input reflection coefficient (s11) and insertion loss (s21). It is clear that the resulting bandwidth equals 230 MHz at a centre frequency of 2.40 GHz, and an s11 of -26 dB. The corresponding insertion loss is equal to -0.8 dB. The two transmission zeros are located at 2.176 GHz and 2.638 GHz, which indicates a sharp cut before and after the passband.

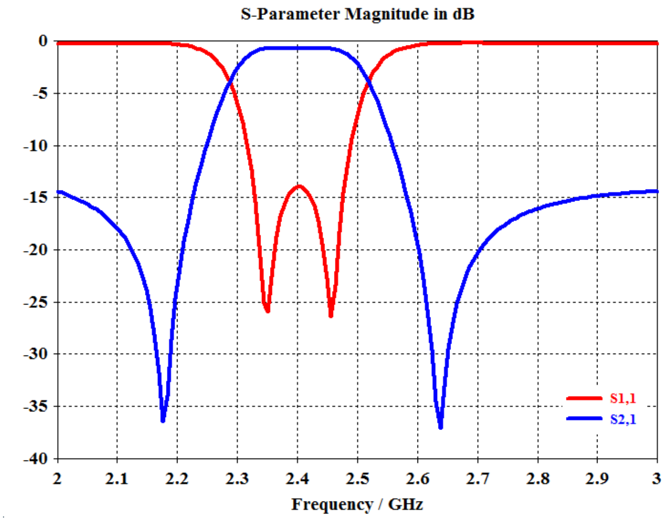


Figure 8. Simulated response input reflection coefficient (s11), and (b) insertion loss (s21) of the proposed filter.

A comparison between the performance of the BPF presented in this paper with that reported in published work [24] is shown in Table 2.

Table 2. Comparison of the presented BPF with published work [24].

Parameter	Center freq. (GHz)	s11	s21	-3 dB BW (MHz)	Filter size λg^2	Overall dimensions λg^2
Presented filter	2.40	-26	-0.8	215	0.19 × 0.14	0.40 × 0.20
Ref. [24]	2.40	-16	-0.9	30	0.24 × 0.27	0.65 × 0.69

4. Conclusions

A Compact Bandpass Filter was introduced in this paper as a new approach to promote compactness in a microstrip bandpass filter based on a polygonal open-loop resonator. The presented resonator element consists of 11 sides of different lengths. Simulation results show that this filter possesses a reasonable input reflection coefficient and insertion loss as well as offering overall filter dimensions of 8×16 mm^2. The presented filter demonstrates enhanced passband behaviour with a centre frequency of 2.40 GHz and fractional bandwidth (FBW) of 10%. The filter is characterized by an input reflection coefficient of –26 dB and insertion loss of -0.8 dB. Two transmission zeros are located at 2.176 GHz and 2.638 GHz, which makes the proposed model very desirable for Bluetooth and WLAN applications (IEEE 802.11n).

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