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Study of Multiband Antenna Design Techniques for Wireless Applications: A Research Review

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Abstract: Now a days, multiband antennas are in greater demand because they allow for the flexibility to combine many wireless communication standards in a single antenna system. Therefore, for the compact communication devices and systems multiband antenna is essential. This paper gives a comprehensive review of various techniques to implement multiband antenna with enhanced parameters, such as compact size, high gain, and superior radiation characteristics for various wireless communication standards.

Keywords: Microstrip Patch Antenna (MPA), Multiband, Defected Ground Structures (DGS), Fractals, Metamaterial, Slots.

I. INTRODUCTION

In the last several years, there have been significant changes to modern wireless communication systems. In the present scenario, antenna is not only transmitting and receiving device but it is also incorporated with other circuit components. Therefore, with the advancement in wireless communication technology there is highly requirement of antennas that are low-weight, compact size, better performance and operate at many frequencies [1]. Multiband antenna has attracted widespread attention because it provides flexibility to combine various wireless communication standards in only one compact system and thereby are advantageous by ensuring compactness, low power consumptions, high data transmission rate, low cost and when compare it with the broadband antenna it can reduce system interference and the superfluous frequency band can be efficiently filtered [2,3]. As increase in demand of multi-functional and multiapplication device, this turns into requirement for multiple antennas in a single device. However, multiband operation is achievable by simultaneously using numerous antennas, but it raises the system's cost and complexity. Additionally, employing several antennas causes the coupling issue, Thus reducing the antenna's performance. Microstrip patch antennas have been well suited for wireless applications because of their characteristics such as simple structure, light weight, small, affordable cost, easy to fabricate and compatibility with Integrated Microwave and Millimeter wave Circuits (MMIC). Also, it can be easily designed to operate in multiband applications. But they suffer from disadvantages like narrow bandwidth and low gain. MPA consists of a ground plane on one side of the dielectric substrate and a radiating patch on the other, along with this there is feeding part which is connected on appropriate place [4]. A multiband antenna operates on a number of frequency bands that are appropriate for a number of applications, including Wi-Fi, WiMAX, Bluetooth, GSM, GPS, satellite communication, RADAR, ISM band applications for household devices, scientific, and industrial systems. [5].

This study aims to provide an overview of the latest research findings on various novel approaches to design efficient compact multiband antenna for wireless applications.

The following are the study's primary contributions:

- Categorization of multi-band antenna operation methods
- Evaluation of each multi-band antenna design technique's performance based on four distinct parameters
- General flow chart of multi-band antenna
- Discussion on the technique which fulfill all the criteria of efficient compact multiband antenna.

II. VARIOUS TECHNIQUES TO ACHIEVE MULTIBAND OPERATION

Ordinary MPA typically resonate on only one frequency band with low gain and minimal bandwidth. To overcome these drawbacks there are many methods/techniques for designing antennas that can support multiple frequency bands simultaneously, while also taking into account other desirable parameters of antenna like small size, low return loss, increased gain and bandwidth for enhance the performance of antenna.

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This section describes several approaches to design such multifunctional multiband antenna. All of these techniques are discussed along with some related examples.

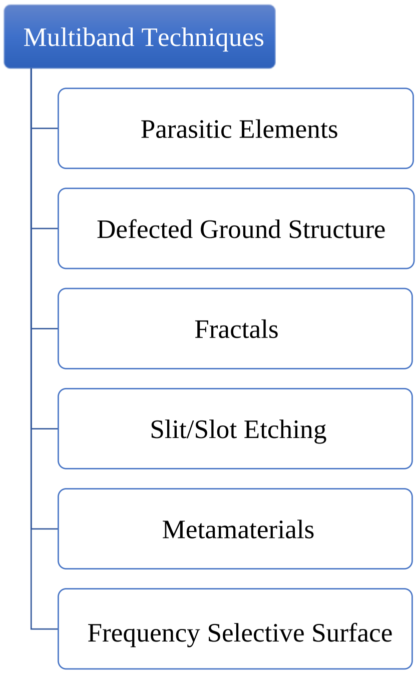

Fig.1 Classification of Multiband Antenna design techniques

A. Parasitic Elements

A parasitic patch is additional radiating patch close to main radiating patch that is not directly powered by a feed transmission line. Current distribution is affected by a parasitic element. As a result, resonance appears at lower frequencies without increasing the antenna's size. Adding parasitic element is a popular technique to attain multiple resonance frequency, better impedance matching, improved gain and bandwidth. It can also eliminate the surface losses resulting in increased radiation efficiency [6]. In Fig.2 multiband functionality is achieved by adding two U-shaped parasitic elements. This antenna design act as a multiband reconfigures antenna. Meaning the designed antenna offers flexibility of the multiband characteristics by suppressing the higher order modes. It gives good impedance matching, low return loss and high gain characteristics. The antenna resonates at frequencies of 2.6 GHz, 6 GHz and 8.5 GHz with high gain of 6.2dBi, 4.52dBi and 6.9dBi respectively. The antenna can be used for WiMAX, vehicular LAN and weather radars.

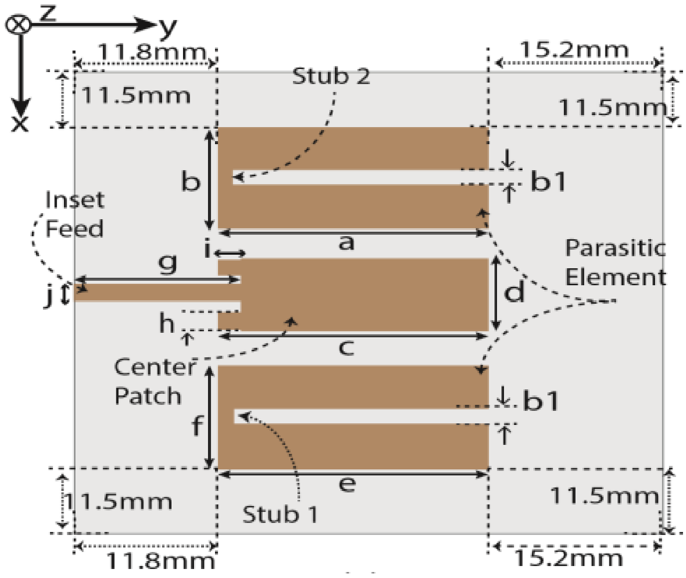

Fig. 2 MPA with two U-shaped parasitic elements [7]

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B. Defected Ground Structure

Defected Ground Structure (DGS) is referred to as intentionally created different shapes of defects or slots in the ground plane. The defects introduced in a ground plane can be single or multiple. The defect on ground plane disturbs ground plane's shielded current distribution; this disturbance affects the transmission line attribute viz. inductance and capacitance. DGS is a popular technique to improve limited bandwidth, cross-polarization, inadequate gain [8]. In addition, DGS is used as an approach to reduce the size, minimise the impact of mutual coupling when using an array and for achieving multiband operation [9]. The compact multiband antenna using DGS has been suggested by Ali, T. *et al.* in [10]. FR-4 substrate has been used to implement the antenna. The antenna consists of elliptical patch and miniaturization and the introduction of E-type unit cell DGS in conjunction with H-shaped slot allows for multiband operation. The antenna has total dimensions of 18×18×1.6mm^3. This antenna able to resonate at 2.56GHz lower WiMAX band, 3.64GHz middle WiMAX band and 5.8GHz WLAN band with return loss less than -10dB. This ground imperfection modifies the antenna's total surface current. Due to this, the surface current's overall path increases leading to the antenna's ability to function at 5.8 GHz, 2.56 and 3.64 GHz. Additionally, the antenna size becomes smaller because of the cascading E-type unit cell DGS structure combined with the H-shaped slot, and each unit cell independently controls a certain set of operating bands. At the desired frequencies, better impedance matching is obtained.

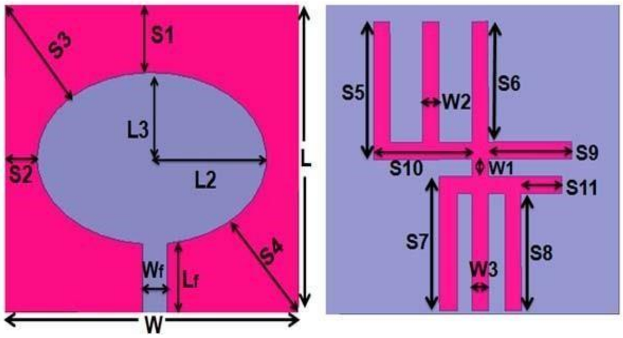

Fig.3 MPA with E-type unit cell with H-shaped DGS [10]

C. Fractals

Fractal geometry is formed by repetition of single pattern over and over in continuing feedback loop. Two characteristics are used to design fractal antennas: self-similarity and space filling. Self- similarity and space filling property is used to miniaturize the antenna [11]. B. Mandelbrot discovered various fractal geometries like Sierpinski, Koch, Hilbert and Minkowski. Iterations are used in the implementation of these geometries. Developing small, wideband, and multiband antennas with significant gain can be greatly facilitated by the usage of fractal-based structures. [12]. The example of fractal antenna is shown in fig.4. The substrate material for the suggested antenna is Rogers RT Duroid 5880 with dimensions of 50×50×0.8mm^3. Elliptical shape patch is used due to its circular polarization characteristics compared to other structures. This proposed antenna resonates at 2.6GHz, 6GHz and 8.2GHz with bandwidth of 410MHz, 1070MHz and 4840MHz respectively. There are several wireless applications for this antenna like Wi-Fi, WLAN and WBAN. Also, it covers X-band and C-band. The antenna contains elliptical shape fractal geometry with DGS. In which, each ellipse with different radius gives a specific frequency to achieve multiband characteristics. In addition, DGS technique is used to achieve wide bandwidth, better gain and to suppress cross polarization.

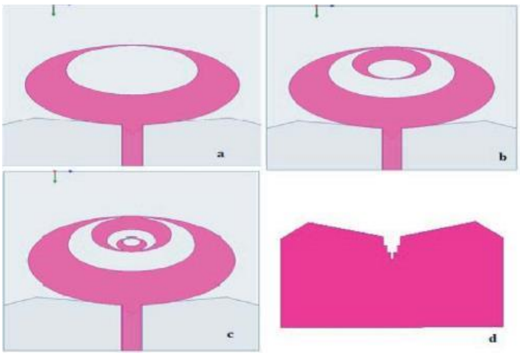

Fig.4 Elliptical shaped fractal iteration with DGS [13]

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D. Slots/Slits

A slot refers to cutting out an area from patch. A concept of using slot in radiating patch alters the surface current distribution. Thus, the total current path length increases this allows the antenna to function at several different frequency bands. . It also provides compactness, better impedance matching, wideband and multiband antenna [14]. Slotted patch-based multiband antenna with DGS has been proposed by Dash, R.K. *et al*. [15]. It comprises of U-shaped patch slots, this facilitates dual band resonance of the antenna along with this, additional resonances in the lower frequency range are produced by DGS implementation. This design gives multiple band response with reduction in cross polarized radiations in E- and H- planes. The term "cross polarization" describes radiation coming from an antenna that is directed in an unwanted direction. By reducing the cross polarized radiations antenna radiation performance can be improved. The proposed antenna resonates at Penta band of frequencies with good performance and compact size.

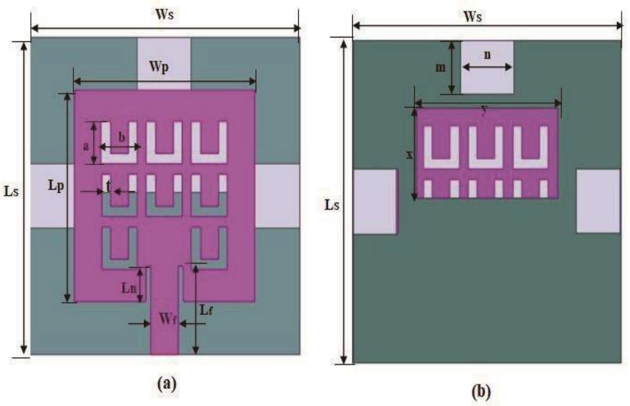

Fig.5 MPA with U-shaped slots and DGS [15]

E. Slots/Slits

Metamaterials are artificially engineered materials that do not occur naturally. We have to design this material as per our requirement. Metamaterials derive their properties not from aspects of their base materials, but from their uniquely engineered structure. It has characteristics like negative permeability and permittivity, which improve the antenna parameters like reduction in dimensions, gain and bandwidth enhancement, low return loss [16]. Multiple frequency operation is also achieved by implementation of different metamaterial structure such as SRR, CSRR [17], Modified Hexagonal Complementary Spiral Resonator (MHCSR) [16], Modified Triangular Split Ring Resonator (TSRR) [18], Complementary Folded Triangle Split Ring Resonator (CFTSRR) [19], and so on. A metamaterial unit cell-based miniature tri-band antenna has been presented [19]. Two complementary Folded Triangle Split Ring Resonator (CFTSRR) metamaterial unit cells and a dumbbell-shaped patch make up the antenna, has total dimensions of 16 × 21mm^2. The proposed antenna resonates at 1.8GHz, 2.4GHz and 5GHz for GSM and Wi-Fi frequency bands of mobile handset applications. Through the introduction of CFTSRRs in radiating patch and ground plane many frequency bands can be resonated by an antenna and size reduction of 88.6% is achieved with high gain.

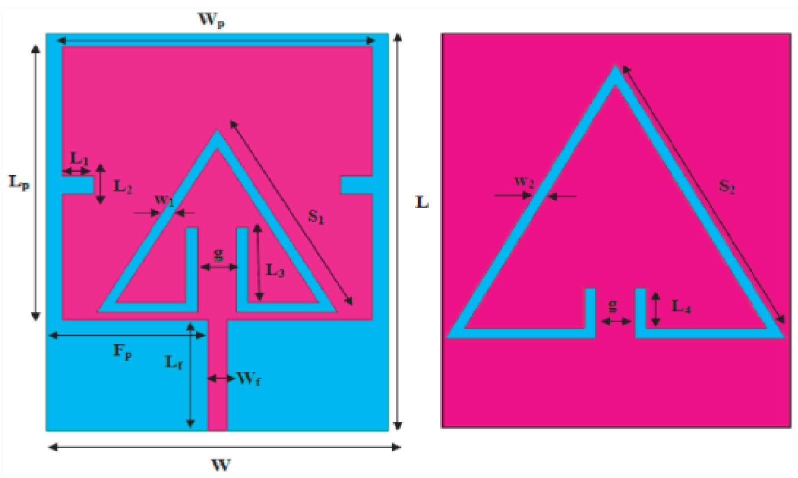

Fig.6 Slotted MPA with SRR and CSRR [19]

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F. Frequency Selective Surface

A periodic surface with a two-dimensional metallic element array (Patch or apertures) on a dielectric substrate is called an FSS (Frequency Selective Surface). It demonstrates transmission of in-band frequency and reflection of out-band frequency depends on the design of array element, thus FSS is identified as a spatial filter.

There are two general geometries of FSS which is shown in fig.7. fig.7(a) refers as capacitive FSS, which transmits low frequencies and reflect high frequencies therefore it is similar to low pass filter. Fig.7(b) shows an inductive FSS, similar to high pass filter.

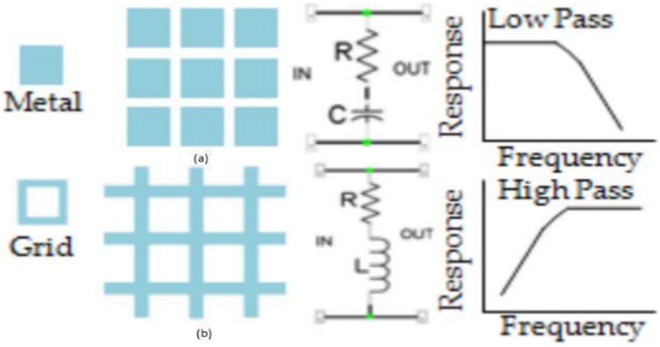

Fig.7 FSS periodic structure (a) a capacitive surface (b) an inductive surface [20]

A miniaturized multiband antenna based on the combination of frequency selective surfaces (FSS) and DGS has been proposed by the authors in [22], as illustrated in fig. 8. It is made up of two layers, comprise a metallic patch on the first dielectric layer and on second dielectric layer 2, there are five concentric circles, along with this a I-shaped slot is etched on a ground plane.

The operating frequency bands of proposed antenna are 5.5GHz, 6.81GHz, and 9.3GHz and covers C-band and X-band applications. Five concentric rings make up the periodic structure, which exhibits FSS behavior and is predicted on the basis of Floquet Port Technique. The size reduction of 81.5% is achieved by using DGS.

Fig.8 8 MPA with FSS and DGS [22]

The shape, size and periodicity of unit cell describe the frequency response [20]. FSS is used in antennas to achieve multiband operation, miniaturization, gain improvement and mutual coupling reduction in case of arrays [21].

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TABLE I COMPARATIVE ANALYSIS OF DIFFERENT MULTIBAND ANTENNA DESIGN TECHNIQUES

S. No	Author [Ref.]	Quality parameters					Technique used	Remarks
		Size (mm^2)	Operating Frequencies (GHz)	Gain (dBi)	Bandwidth (MHz)	S11 (dB)		
1	Asif *et al.* [7]	40 × 30	2.6, 6, 8.5	6.2, 4.52, 6.9	50, 22.8, 30	-	Adding parasitic elements	Parasitic patch increased the size of antenna
3	Kaur *et al.* [13]	50 × 50	2.6, 6, 8.2	5.42, 6.52, 7.67	410, 1070, 4840	-18.18, -15.11, -16.33	Fractals	Provide wide bandwidth and high gain but the complexity involved in the design and manufacturing process
4	Dash *et al.* [15]	30 × 30	2.5, 5.49, 6.06, 7.71, 9.08	3.07, 3.04, 4.57, 4.88, 4.90	120, 70, 130, 610, 180	-16.59, -15.40, -35.54, -18.30, -25.99	Introduce Slots	Antenna resonates for 5 frequency bands, simple to implement
5	Rajalakshmi*et al.* [19]	16×21	1.8, 2.4, 5	1.7, 8, 11.5	250, 50, 225	-24, -19, -18	Metamaterial Structure	Metamaterial structure provide highly miniaturized antenna with high gain
6	Sah *et al.* [22]	25×24.86	5.5, 6.81, 9.3	2.42, 2.80, 6.76	200, 300, 1000	-34, -32, -39	Frequency Selective Surfaces	The combination of FSS and DGS technique is used for multiband as well as miniaturize the antenna

III. MULTIBAND ANTENNA DESIGN FLOWCHART

In the proposed design we wish to develop an antenna which will have all the features like compactness, multiple frequency operation, good performance parameters like gain, bandwidth, return loss, VSWR, directivity. The design flow for the development of multiband antenna that can be further modified as following (Fig. 9).

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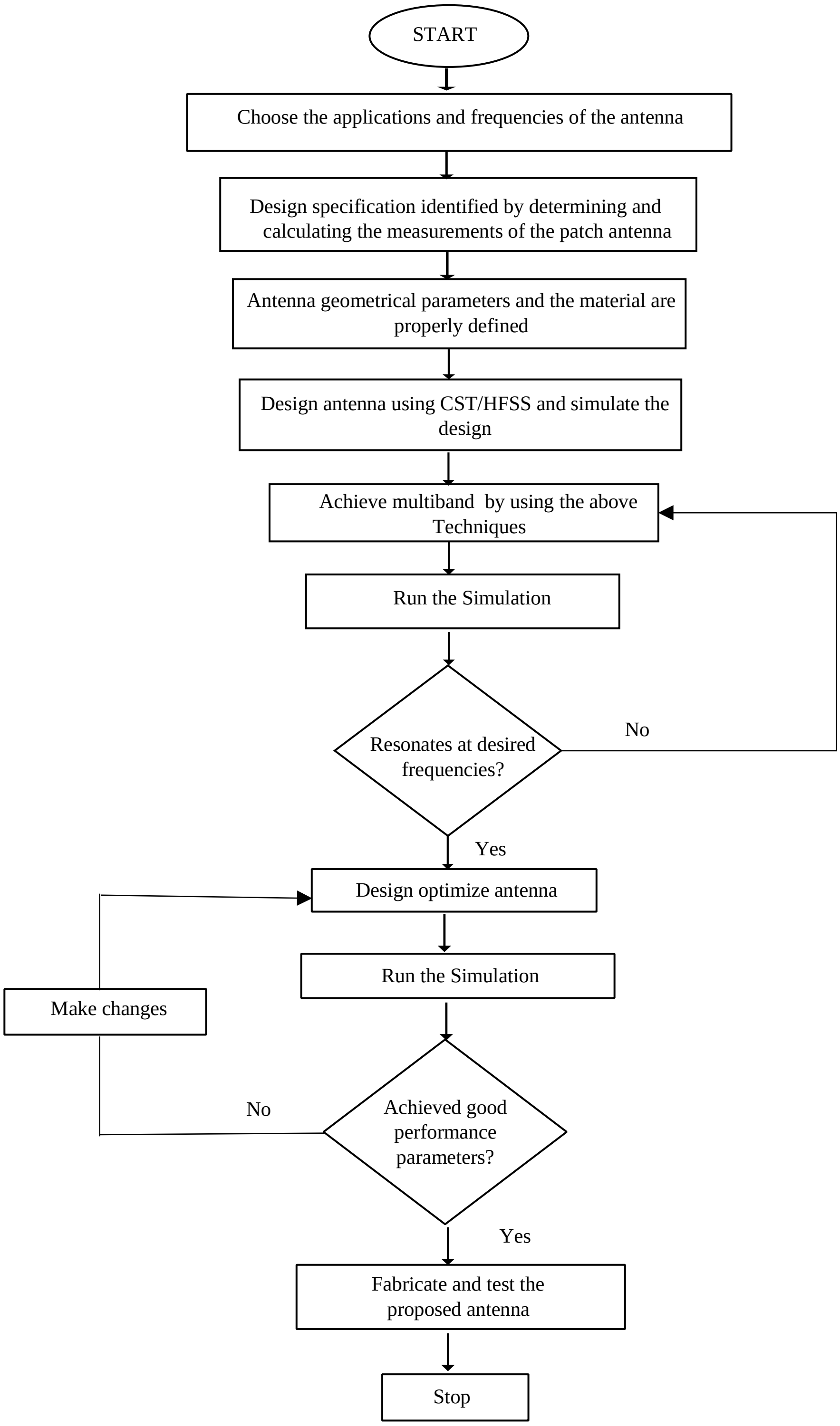

Fig.9 Flow chart of antenna design steps

IV. CONCLUSION

This paper presented a comprehensive review of various techniques to design multiband antenna. All the techniques are explained with related examples. Along with multiband operation it should provide compact size and better performance parameters like gain, bandwidth, return loss, efficiency, VSWR, directivity etc. for further advancement. To design multiband antenna the effect of parasitic elements, slots/slits, FSS, metamaterial, DGS and Fractals were discussed with related examples. In Table 1, relevant work on different multiband design techniques is compared in terms of size, bandwidth, gain, and return loss. After reviewing all of antennas it is seen that for metamaterial

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technique, antenna shows higher miniaturization also multiband characteristics with high gain which fulfill the criteria of designing compact multiband antenna. For the fractal technique, the antenna shows wide bandwidth and high gain but the complexity is increase in designing and manufacturing process. Etching slots techniques are very simple to implement and provide the desired resonate bands but it induces back lobe radiation. The technique proposed in [22] is the combination of frequency selective surface and DGS. In addition to multiband operation the combination of these techniques gives good performance as well as miniaturization.

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