# A Novel Compact UWB Monopole Antenna with Triple Band-Notched Characteristics with EBG Structure and Two Folded V-slot for MIMO/Diversity Applications

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***Abstract*** **─** A novel compact, ultrawideband (UWB) monopole antenna with triple band-notched characteristics are presented for MIMO/diversity applications. Triple band-notched function is achieved by inserting two folded v-slot on the radiation patch and two modified mushrooms-like EBG structure above ground plane on either side of feed line. The designed MIMO antenna has a small size compared to the previous similar designs. With the purpose of mutual coupling reduction between antenna elements, two rows of modified mushroom-like EBG structures are inserted to suppress the effect of the surface wave between antenna elements. The MIMO performance of the proposed antenna is studied through mutual coupling (S12), envelope correlation coefficient (ECC) and diversity gain.

***Index Terms*** **─** EBG, MIMO monopole antenna, triple band-notch, Ultrawideband (UWB).

## I. INTRODUCTION

Recently, multiple input multiple output (MIMO) systems have been received more attraction due to having good capabilities such as robustness against multipath fading, improvement of channel capacity and spatial diversity gain required for high data rate communication links [1]. In theory, the capacity of channels can be increased linearly with the number of elements; however, in practice mutual coupling between elements reduces channel capacity [2]. Therefore, it will be a major challenge to reduce mutual coupling in MIMO systems. The more distance is between inter-elements, the lower mutual coupling will be in result, but the size of the antenna will be increased undesirably. Several methods have been proposed to reduce mutual coupling between inter-elements in compact MIMO antennas based on diminishing surface waves. Employing the lossy material is proposed in [3], A quarter-wavelength slot are used in [4], single negative magnetic (MNG) metamaterials have been proposed in [5,6], defected ground structures (DGS) are used in [7,8], radial stub loaded resonator are employed in [9] and mushroom-like EBG structures are used widely in recent researches [10-13]; however, utilizing two or more rows of these structures will increase the size of MIMO antenna, so to decrease the size of mushroom-like EBG a method of moving the via off the center proposed in [14]. This method is employed in this paper to modify mushroom-like EBG structure.

To achieve higher data transfer rate communication links, it is required that the MIMO antenna should be suitable for UWB applications. However, the frequency range of 3.1 GHz to 10.6 GHz for UWB systems will cause interference to the existing wireless communication systems, such as, the wireless local area network (WLAN) for IEEE 802.11a operating at 5.15 GHz – 5.35 GHz and 5.725 GHz – 5.825 GHz bands, WiMAX (3.3 GHz – 3.6 GHz), C-band (3.7 GHz – 4.2 GHz) and X band uplink frequency band from 7.9 to 8.4 GHz; so the UWB MIMO antenna with a single, dual and triple band-stop performance is required. There are various methods to achieve band-notched characteristic for printed monopole antennas. The most popular approach is cutting different shaped slots in radiating patch or in its ground plane, the slots using U-shaped [15], a square [16], a trapezoidal shaped [17], an H-shaped [18] have been proposed and recently mushroom-like EBG structures have been used in [19-22]. Communication systems usually require smaller antenna size in order to meet the miniaturization requirements of radio-frequency (RF) units [23]. Nevertheless, most of these antennas have the common deficiency of large size, which may lead to a challenging task in miniaturizing antenna design.

In this letter, a novel triple band-notched MIMO antenna with reduction in overall size is proposed. The size of the proposed antenna is smaller than the MIMO antennas with band-notched function reported recently in [25-30]. This paper is organized as follows: the single monopole antenna configuration is presented in Section II. Section III is followed in two parts A and B, part A discusses triple band notch characteristic of the single

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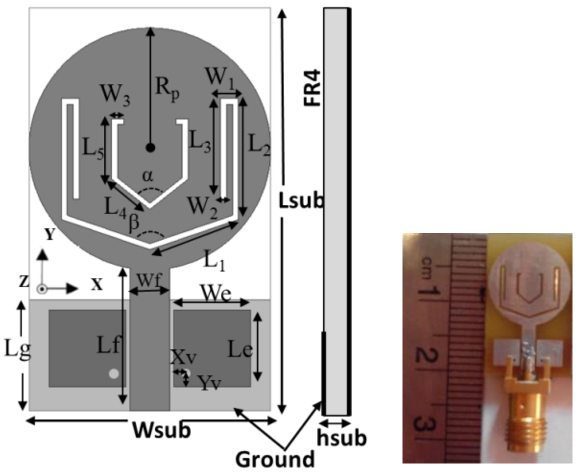
monopole antenna and part B discusses MIMO application of the proposed antenna through simulated and measured results. Finally, this letter is concluded with a brief summary in Section IV.

## II. ANTENNA DESIGN

The geometry and configuration of the proposed microstrip-fed monopole antenna is illustrated in Figs. 1 (a) and (b). This antenna is fabricated on the commercially cheap FR4-epoxy substrate with εr = 4.4, tan (δ) = 0.024 and dimensions of 12×20×1.6 (=h) $mm^3$. The width of the microstrip feed line is fixed at 2 mm and is connected to a 50 Ω SMA connector. The optimized values of proposed antenna design parameters are given in Table 1.




(a) (b)

Fig. 1. Triple band notched monopole antenna: (a) geometry and (b) configuration.

Table 1: Parametric values of proposed antenna

| Param. | mm | Param. | mm | Param. | mm |
|---|---|---|---|---|---|
| Wsub | 12 | Xv | 0.7 | L3 | 5 |
| Lsub | 20 | Yv | 0.7 | L4 | 2.42 |
| hsub | 1.6 | g | 0.2 | L5 | 3 |
| Wf | 2 | W1 | 0.9 | Rp | 3.3 |
| Lf | 7.1 | W2 | 0.3 | α | 103 |
| Lg | 5 | W3 | 0.9 | β | 142 |
| We | 3.8 | L1 | 4.65 | | |
| Le | 3.8 | L2 | 6 | | |

The basic antenna structure is a circular patch with a radius of R is printed on the top side of the dielectric substrate. To obtain the triple band-notched function two folded v-slots are embedded in the radiation circular patch and two modified mushroom-like EBG structures implemented symmetrically on both sides of the microstrip feed line above the ground plane. On the other side of the substrate, the conducting ground plane with a length of 5 mm covers only the section of the microstrip feed line.

## III. RESULTS AND DISCUSSIONS

### A. Triple band notch monopole antenna

The performance of the proposed antenna in parametric studies has been investigated to find optimized parameters using the Ansoft High Frequency Structure Simulator Software (HFSS, ver. 15) based on the finite element method (FEM). In the simulation setup perfect electric conductor (PEC) and an ideal excitation port are assumed.

To describe the design process, four prototypes of the proposed antenna are defined as follows (Fig. 2): AntI is a typical monopole antenna with a circular patch fed by microstrip line; in AntII, two modified off center mushroom-like EBG structures are used symmetrically on both sides of the microstrip feed line above the ground plane; AntIII includes a folded v-slot embedded in the circular patch and AntIV contains second folded v-slot inserted in the circular patch.

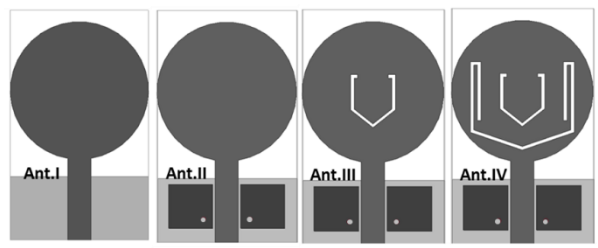



Fig. 2. Four improved prototypes of the proposed antenna.

Figure 3 presents simulated VSWR characteristic for four designed prototypes of the proposed antennas. As shown in Fig. 3, UWB impedance bandwidth can be simply achieved for Ant.I by adjusting length of ground plane (Lg = 5).

To provide band rejection around 5.1-6 GHz (WLAN band), two modified mushroom-like EBG structures employed on either side of the feed line symmetrically shown in Fig. 4 (a). Normally EBG unit cell is composed of a rectangular conductive patch and one shorting via placed at the center that connects the patch and the ground plane together. An equivalent-circuit model [24] of the EBG structure is shown in Fig. 4 (b).

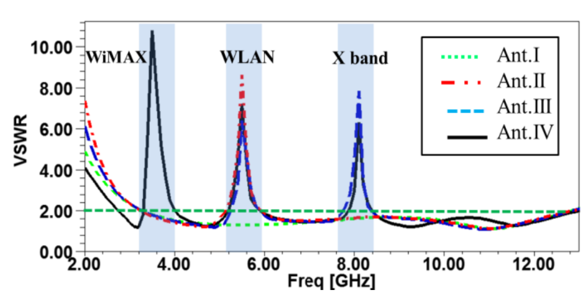
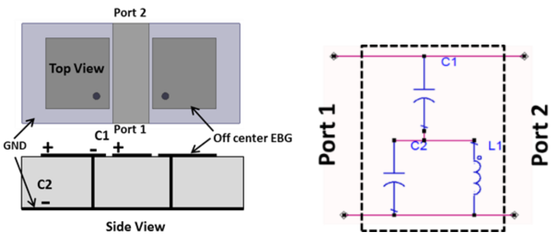



Fig. 3. Simulated VSWR of four designed prototypes of the proposed antenna.




(a) (b)

Fig. 4. (a) Two modified mushroom-look EBG structure on the either side of microstrip feed line; and (b) equivalent circuit.

The resonant frequency of the EBG cell can be obtained by:

$$fn = 1/2\,\pi\sqrt{L\,(\,C1 + C2\,)}, \tag{1}$$

$$C_1 = \frac{W\varepsilon_0\left(1+\varepsilon_1\right)}{\pi}.\cosh^{-1}\left(\frac{w+g}{g}\right), \tag{2}$$

$$L = \mu h, \tag{3}$$

where $C_1$ owes to the voltage gradients between the patch and the ground plane at normal mushroom EBG structure, $C_2$ is the coupling capacitance between the rectangular EBG structure and the feed line, and the inductance L is due to the current flowing through the via. The band gap region of EBG structure can be shown by dispersion Brillouin diagram where no mode is propagated and it can be simulated with HFSS eigenmode solver. A unit cell of EBG structure with master slave boundary is shown in Fig. 5. By adjusting parameters' value of typical mushroom-like EBG structure, desired band notch can be obtained around 5.5 GHz for $w_e = le = 6.5$ mm; but the width of mushroom is larger than the width of antenna ground ($lg = 5$), so with the aim of miniaturizing EBG structure, the position of via is moved off the center of the patch [14] and subsequently the resonant frequency is reduced to 3.3 GHz, therefore by fixing notch frequency on 5.5 GHz the value of $w_e$ will be reduced to 3.8 mm and the structure of mushroom-like EBG will be modified. The band gap region of modified mushroom-like EBG structure is shown in Fig. 6. It can be seen that band gap is from 5.1 GHz to 6 GHz.

To realize dual band-notch characteristic, a folded v-slot is embedded in the radiation patch of Ant.II where the length of slot can be obtained approximately from the following formula:

$$L = \frac{C}{4 \times f \times \sqrt{\dfrac{\varepsilon r + 1}{2}}}, \tag{4}$$

where f is the center frequency of the band-notch.

To realize triple band-notch characteristic, third band rejection around 3.3-4 GHz (WIMAX band) can be achieved by inserting the second folded v-slot on the radiation path indicated in Ant.IV. At the notch frequencies, current is dominant around slots and is directed oppositely. Accordingly, the radiation fields generated by the oppositely directed currents cancel each other at the notch frequencies, thus notch bands will be achieved.

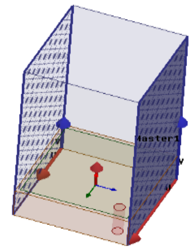


Fig. 5. A unit cell of EBG.

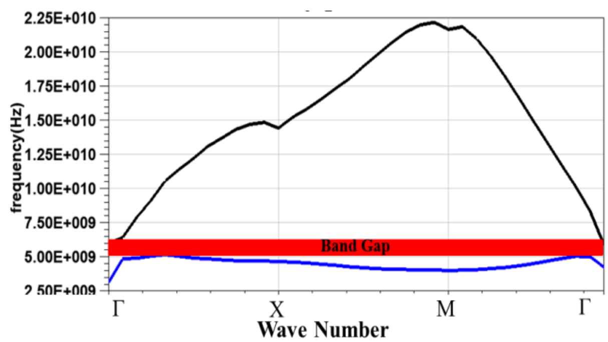



Fig. 6. Dispersion Brillouin diagram of the modified mushroom-like EBG structure.

To further explain the relation between antenna geometry and its triple band-notch characteristic, parametric study was carried out through different values of L3, Le, L5 correspond to first, second and third rejection bands respectively and the results are presented in Fig. 7 (a) to Fig. 7 (c). Figure 7 (a) shows the effect of change in L3 for 5 mm, 3.5 mm, 2.5 mm. By decreasing the value of L3, only the first band-notch shifts to high frequencies and two other band notches stand almost still. As shown in Fig. 7 (b), by decreasing the value of Le from 3.8 mm to 1.8 mm, only second band-notch shifts to up frequencies and the others do not change; and as shown in Fig. 7 (c), by decreasing the value of L5 from 3 mm to 1 mm, only third band-notch shifts up and the others do not change. As a result, we can control the notched frequencies independently by changing the values of L3, Le and L5.

Figure 8 shows the co-polarized and cross-polarized normalized radiation patterns of the proposed antenna measured and simulated at two sample frequencies of 4.5 and 9.5 GHz of E-plane (YZ-plane) and H-plane (XZ-plane). It can be seen that the dipole-like radiation patterns in XZ-plane are nearly omnidirectional for the two frequencies.

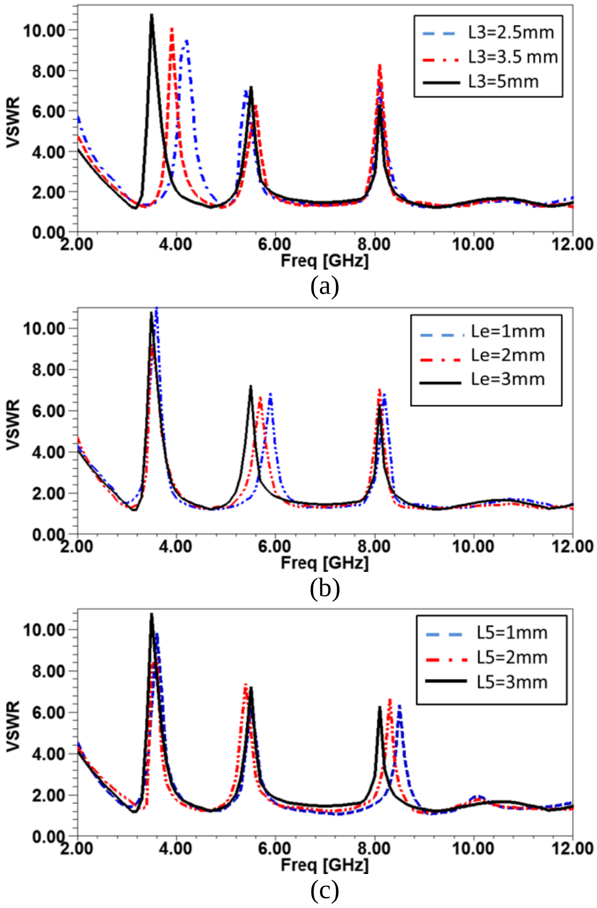



Fig. 7. Simulated VSWR of the proposed antenna with different values of: (a) L3, (b) Le, and (c) L5.

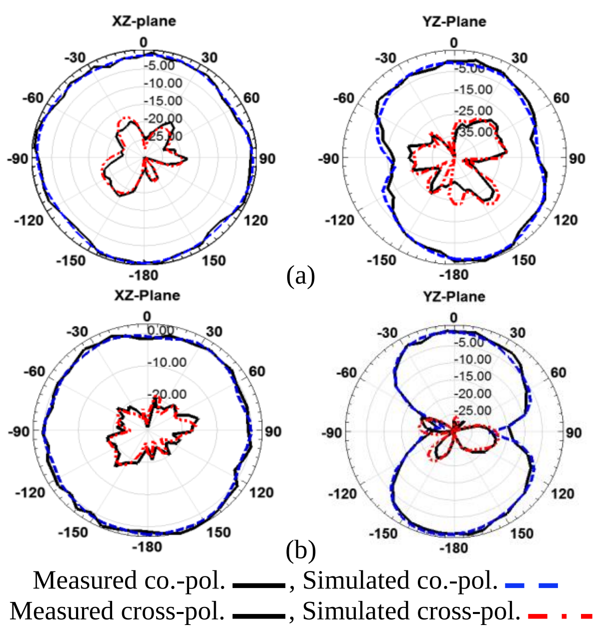



Fig. 8. Measured and simulated radiation patterns of the proposed antenna: (a) 4.5 GHz and (b) 9.5 GHz.

Figure 9 presents the effects of the inserted slots in radiation patch and EBG structures on the measured peak gain of proposed antenna in comparison with the simple monopole antenna without any slot (Ant.I). As illustrated in Fig. 9, the gain of proposed antenna decreases drastically at the notched frequencies band of 3.6, 5.5, 8.1 GHz, for other frequencies outside the notched frequencies band, the measured gain of the proposed antenna is similar to the basic antenna (Ant.I). Figure 9 shows that the inserted slots and EBG do not impose much negative effect on the antenna's radiation.

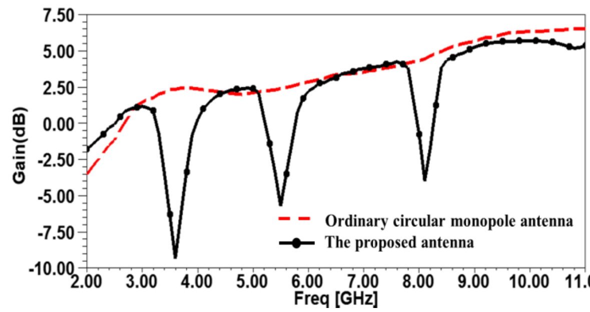



Fig. 9. Measured peak gain of proposed antenna with comparison to simulated gain of ordinary circular patch monopole antenna (Ant.I).

In Table 2, the size of proposed antenna has been compared with similar antennas proposed recently in [25-30]. As illustrated in Table 2, the proposed antenna has advantage of small size compared to others.

Table 2: Comparison of dimension of recently proposed antennas and this proposed antenna

| Ref. | Width | Length | Relative Permittivity |
|---|---|---|---|
| [25] | 35 | 35 | 4.4 |
| [26] | 19 | 24 | 4.4 |
| [27] | 33 | 28 | 4.4 |
| [28] | 18 | 20 | 4.4 |
| [29] | 26 | 36.6 | 4.4 |
| [30] | 24 | 30 | 4.4 |
| Proposed antenna | 12 | 20 | 4.4 |

**B. Realization of diversity/MIMO antenna with mutual coupling reduction**

The configuration of the proposed MIMO antenna is shown in Fig. 10. To achieve antenna diversity feature, two elements of proposed triple band notched monopole antenna are combined in optimized distance of about quarter wavelength ($\lambda g/4$) of 2.24 GHz [31]. For MIMO applications, we need low value of mutual coupling between two antennas, so it can be reduced significantly by employing EBG structures between antennas. As shown in Fig. 10, to reduce mutual coupling two rows of modified mushroom like EBG structures embedded between two antennas with the same dimensions of notch EBG structure mentioned above. Simulated and measured results of mutual coupling (S12) between two antennas with and without EBG structure is presented in Fig. 11. As shown in Fig. 11, without using EBG structure mutual coupling between antennas is high, and even at some frequency ranges it exceeds -15 dB, while by using EBG the mutual coupling between antenna elements will be reduced to below -20 dB, therefore a reduction of about 5~10 dB achieved. It also can be seen that there is close correspondence between measured and simulated results.


Fig. 10. MIMO antenna configuration with two rows of EBG structures.

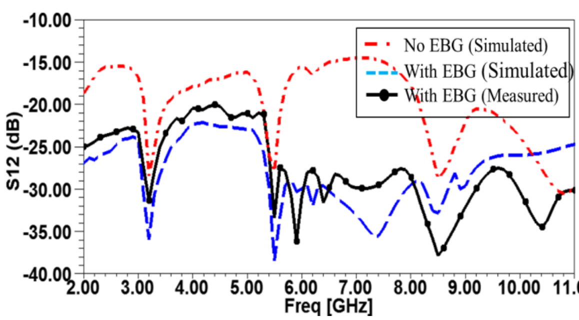



Fig. 11. Mutual coupling between antenna elements with and without EBG structure.

To verify the capability of multi antenna systems for MIMO and diversity application, envelope correlation coefficient (ECC) is an important figure of merit. The ECC, by measuring correlation factor between antenna elements shows the multipath propagation's effect of RF signals received by multi antenna systems. The ECC value can be calculated by fundamental Equation (5) based on consideration of the radiation pattern of each element [32]:

$$\rho_e = \frac{\left|\iint_{4\pi}\left[\overline{F_1}(\theta,\varphi).\overline{F_2}(\theta,\varphi)\right]d\Omega\right|^2}{\iint_{4\pi}\left|\overline{F_1}(\theta,\varphi)\right|^2 d\Omega \iint_{4\pi}\left|\overline{F_2}(\theta,\varphi)\right|^2 d\Omega}, \qquad (5)$$

where $F_1$ is the radiation pattern of Ant.1 where Ant.2 is terminated to 50 ohm, and $F_2$ will be the radiation pattern of Ant.2 where Ant.1 is terminated to 50 ohm.

Another approach to compute ECC is a simple closed form Equation (6) based on S-parameter given in [33]. The measured value of ECC is shown in Fig. 12. The maximum value of ECC is 0.003 which is as expected, due to high isolation between two antennas, which is less than the recommended value of 0.5 in [34]; then it can be deduced that the proposed antenna is more suitable for MIMO application:

$$\rho = \frac{\left|S_{11}^{*}S_{21} - S_{12}^{*}S_{22}\right|^2}{\left(1-\left|S_{11}\right|^2-\left|S_{21}\right|^2\right)\left(1-\left|S_{22}\right|^2-\left|S_{12}\right|^2\right)}. \qquad (6)$$

The diversity gain can be computed in terms of correlation coefficient as given in [35]:

$$G_{app} = 10 * \sqrt{1-|\rho|}. \qquad (7)$$

The calculated value of diversity gain is presented in Fig. 13 which is very close to 10.

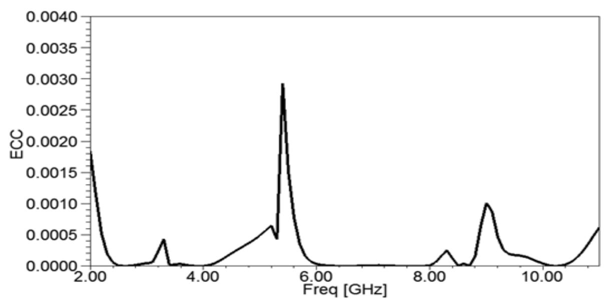



Fig. 12. Envelop correlation factor (ECC) of the proposed antenna.

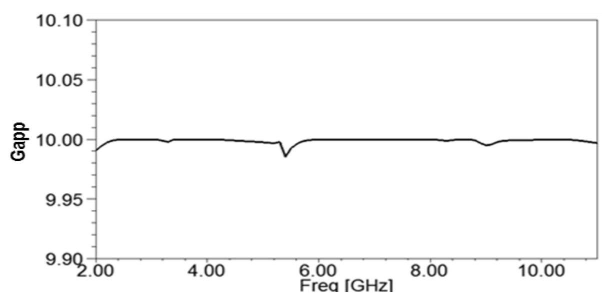



Fig. 13. Diversity gain of proposed antenna.

## IV. CONCLUSION

A novel very compact printed MIMO antenna with triple band-notched characteristic has been proposed and implemented. The antenna includes two miniaturized monopole antennas, which by inserting two folded v-slot in the radiating patch and two modified mushroom-like EBG structures on either side of feed line, triple band-notched characteristic has been achieved. The proposed antenna has a good omnidirectional radiation pattern throughout the UWB frequency range and shows almost flat gain in the operating frequency band with sharp notched bands at rejected bands. To reduce mutual coupling, two rows of modified mushroom-like EBG structures implemented between two antennas. The capability of the proposed antenna for MIMO application has been verified by studying mutual coupling (S12), envelope correlation coefficient (ECC) and diversity gain. Measured results shows that the proposed antenna has low mutual coupling (less than -20 dB) and low ECC (less than .003) which is suitable for MIMO applications. The designed antenna has a small size compared to the previous similar designs.

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