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Bandwidth enhancement for QMSIW antenna by using dual cavity and triangle slot

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***Abstract*—The miniaturization of substrate-integrated waveguide (SIW) antenna suffers from the narrow impedance bandwidth. It occurs on the quarter mode substrate integrated waveguide (QMSIW) antenna that has 75% miniaturization of the full mode SIW. This research proposed the bandwidth enhancement for QMSIW antenna by using dual cavity and triangle slot. The QMSIW antenna feeds in a single port. The impedance bandwidth simulation has an 8.6% fractional bandwidth improved with dual resonant frequencies. The simulation result was validated with the measured impedance bandwidth.**

***Keywords*—dual resonant frequencies; QMSIW; dual cavity; triangle slot; bandwidth enhancement**

I. Introduction

TELECOMMUNICATIONS technology is rapidly advancing to meet human needs, driving intensive research into various components, including antennas. Among these, low-profile, compact, and broadband antennas, particularly those based on system-on-substrate (SoS) technology [1], have become a fascinating area of study for filter [2], antenna [3], and many more. Substrate integrated waveguide (SIW) antennas emerge as a promising solution, offering a low-profile design with a high-quality factor [4]. SIW also offers easily miniaturization by subdividing symmetrically the full mode SIW (FMSIW) into sub-cavities as shown in Fig. 1. Dividing an FMSIW (Fig. 1(a)) into two parts provides 50% miniaturization where each part is called a half-mode SIW (HMSIW) [5]–[7] as shown in Fig. 1(b). In comparison, 75% miniaturization can be achieved if an FMSIW is divided into four parts, and each part of the four parts is called a quarter-mode SIW (QMSIW) [8]–[10] as shown in Fig. 1(c). Dividing a QMSIW into two parts symmetrically becomes an eight-mode SIW (EMSIW) [11] which provides 87.5% miniaturization of an FMSIW. The 93.7% and 98.44% miniaturization of an FMSIW can be achieved by using the same method of miniaturization that resulted in the sixteenth-mode SIW (SMSIW) [12]–[14] and the sixty-fourth mode SIW (SFMSIW) [15]. All of this research gives a compact antenna with a small dimension. However, sub-cavities of SIW with a dominant mode often suffer from narrow impedance bandwidth.

Many researchers proposed bandwidth enhancement methods for solving the narrow bandwidth like coupling techniques [16], [17], modified slot designs [18]–[21], or dual-cavity configurations [22], [23]. The coupling technique occurs between at least two adjacent sub-cavities. The adjacent sub-cavities can use different sub-cavities or the same sub-cavities as reported in [16], and [17]. The 16.2% fractional bandwidth can be achieved by using a coupled technique as reported in ref. [17]. However, the gap fabrication process between two sub-cavities has to be considered.

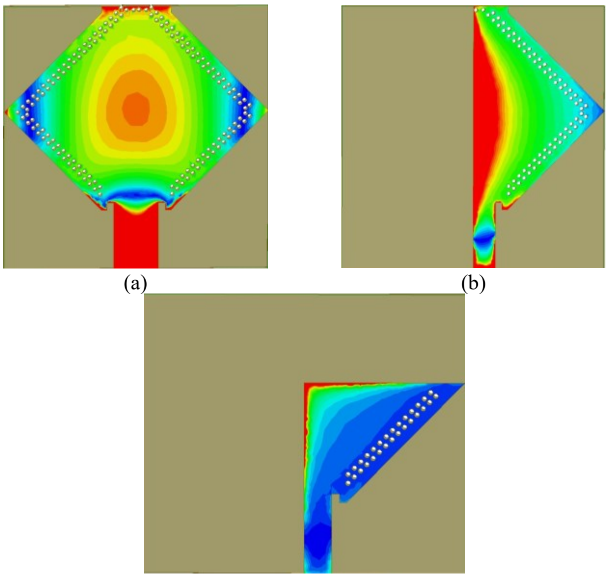
(a) (b) (c)

Fig. 1. The dominant mode electric field distribution for (a) FMSIW (b) HMSIW (c) QMSIW.

The slot modification can be used for another bandwidth enhancement method as reported by ref. [18]–[21]. The 13.2% fractional bandwidth is achieved successfully by using HMSIW sub-cavity. However, the sub-cavity used has to be considered because of the limited space for slot placement and the availability of electric field distribution.

Ref. [22] and [23] use the dual-cavities SIW method for resulting bandwidth enhancement. The broadband bandwidth enhancement (31.83%) is achieved by using this method. However, the dual-cavity SIW method with one feed is rarely

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used because it is difficult to define the transverse electric (TE) modes or transverse magnetic (TM) mixed modes.

This paper proposed the dual-cavities SIW method for narrow impedance bandwidth solution of TE_{101} mode in the ref. [24], by using the same sub-cavities. Two sub-cavities in the QMSIWs are used for generating resonant frequencies that are close together and merge to enlarge impedance bandwidth.

II. Antenna Design

The proposed antenna design named Antenna-3 is shown in Fig. 2(c). The proposed antenna design comes through by antenna evolution as shown in Fig. 2, while the reflection coefficient simulation for the antenna evolution is shown in Fig. 3. The antenna evolution starts with Antenna-1 which only has a single cavity with a single resonant frequency. The resonant frequency of Antenna-1 is set by using equation (1) [25], while the QMSIW structure is used for FMSIW miniaturization that has been described before.

$$f_{mnp} = \frac{c}{2\pi}\sqrt{\left(\frac{m}{L_{eff}}\right)^2 + \left(\frac{n}{h}\right)^2 + \left(\frac{p}{W_{eff}}\right)^2} \qquad (1)$$

The diameter vias (dv) are 0.5 mm and the distance between two adjacent vias (pv) is 1.5 mm. It is necessary to meet the criteria of dv/pv values being equal to or greater than 0.5 and dv/λ_0 values being less than or equal to 0.1, where λ_0 represents the wavelength in free space [26].

All antennas design is formulated in the fabrication substrate i.e. Rogers 5880 with 1.575 mm of thickness (h), 2.2 of permittivity (ε_r), and 0.0009 of tangent loss (δ). By using Ansys HFSS 3D electromagnetic simulation software, all antennas are designed.

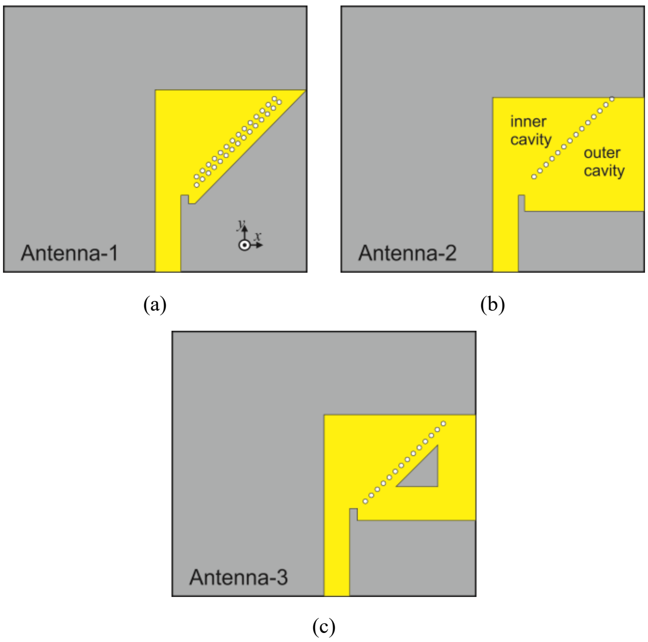


Fig. 2. Antenna evolution: (a) QMSIW with a single cavity (Antenna-1), (b) dual-cavities QMSIW (Antenna-2), and (c) dual-cavities QMSIW with a triangle slot (Antenna-3).

A. Antenna Evolution

Antenna-1 has a 170 MHz impedance bandwidth that resonant on 5.13 – 5.30 GHz. By adding another resonator patch on the other side, Antenna-1 becomes Antenna-2. The dual cavity with the same QMSIW sub-cavities is implemented into Antenna-2. Antenna-2 has dual-band resonant frequencies as shown in Fig. 3. The lower frequency resonant is achieved by the outer QMSIW which has a larger dimension rather than the inner QMSIW. Each resonant frequency has a narrow impedance bandwidth with 2.92% (4.72 – 4.86 GHz) and 4.01% (5.37 - 5.59 GHz). A narrow impedance bandwidth of Antenna-2 is improved by a triangular slot addition named Antenna-3. The triangular slot is placed in the middle of the outer QMSIW. Dual-band resonant merger in the middle to enlarge impedance bandwidth twist than before. Antenna-3 has an 8.59% fractional bandwidth that resonant on 4.90 – 5.34 GHz (440 MHz). The final Antenna-3 dimension is illustrated in Fig. 4, and the dimension is tabulated in Table I.

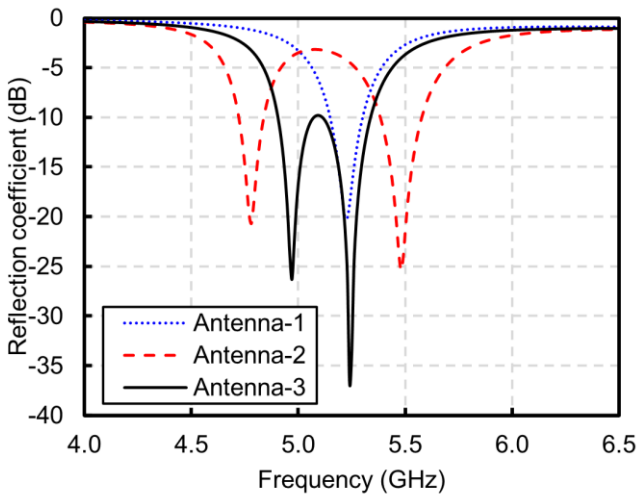
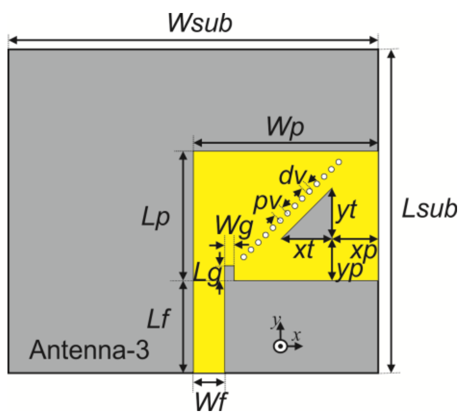


Fig. 3. Reflection coefficient of antenna evolution.

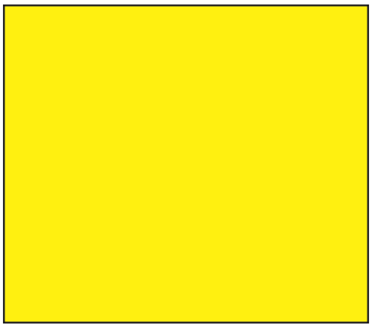
TABLE I
ANTENNA-3 DIMENSION

Wsub	40	*Wf*	3.4	*xp*	5
Lsub	35	*Lf*	10	*yp*	4.5
Wp	20	*Wg*	1	*xt*	5.5
Lp	14	*Lg*	1.6	*yt*	5.5

all unit in mm



(a)

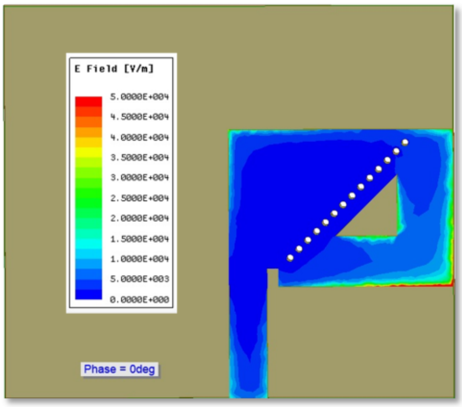


(b)

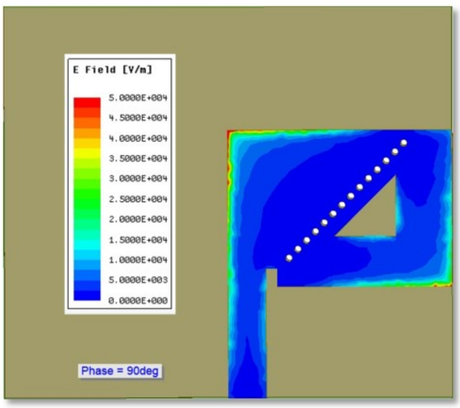
Fig. 4. The Antenna-3 proposed design (a) the top layer, and (b) the ground layer.

B. Electric Field Distribution

Antenna-3 has dual resonant that resonate on 4.97 and 5.24 GHz. The lower frequency (4.97 GHz) is influenced by the large resonator that is the outer cavity as shown in Fig. 5. The electric field distribution of TE_{101} mode is shown by the phase differentiation between 0 and 90 degrees as shown in Fig. 5(a) and Fig. 5(b). The inner cavity influenced the higher frequency (5.24 GHz) which has a small resonator than the outer cavity. It also is approved by electric field distribution as shown in Fig. 6(a) and Fig. 6(b) for TE_{101} mode.

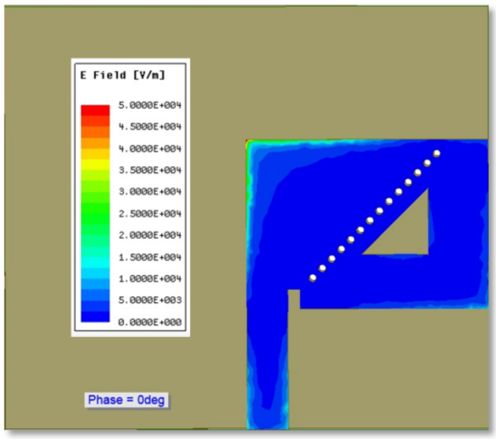


(a)

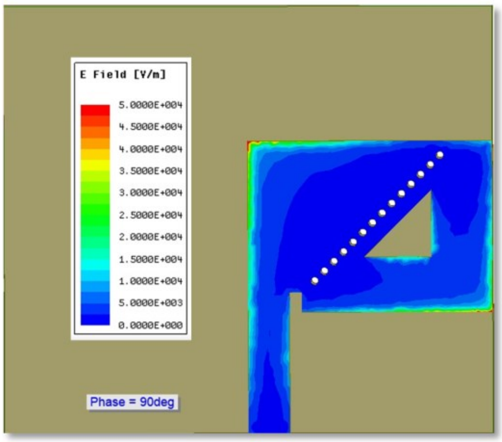


(b)

Fig. 5. Electric field distribution of the Antenna-3 on frequency 4.97 GHz at phase (a) 0 degrees, and (b) 90 degrees.



(a)



(b)

Fig. 6. Electric field distribution of the Antenna-3 on frequency 5.24 GHz at phase (a) 0 degree, and (b) 90 degrees.

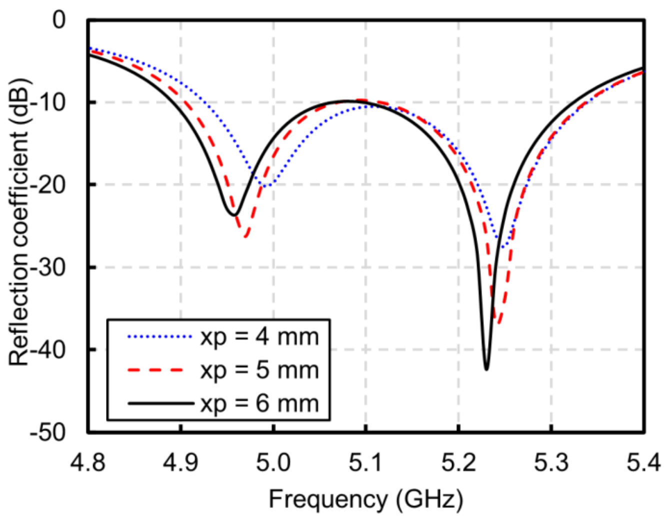


Fig. 7. Study parametric of *xp* variable.

C. *Parameters Studies*

Bandwidth enhancement of the proposed antenna design is influenced by the triangular slot position viz. *xp* and *yp* variables as shown in Fig. 7 and Fig. 8. Fig. 7 shows that the lower frequency and the higher frequency move into lower frequency as the triangular slot shift into left position. Fig. 8 shows the lower frequency and the higher frequency move into the higher frequency when the triangular slot shifts into the down position. Furthermore, the triangular slot size also influenced the bandwidth enhancement, viz. *xt* and *yt* variables as shown in Fig. 9. It shows the dual resonant frequencies disappear when the triangular slot size is too small and big.

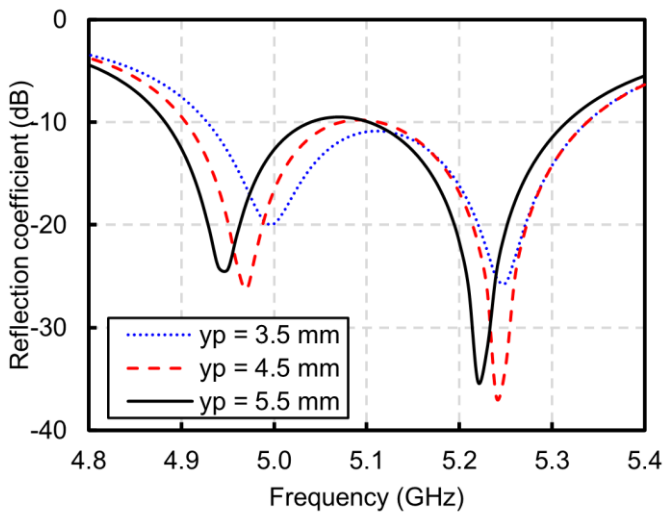


Fig. 8. Study parametric of *xp* variable.

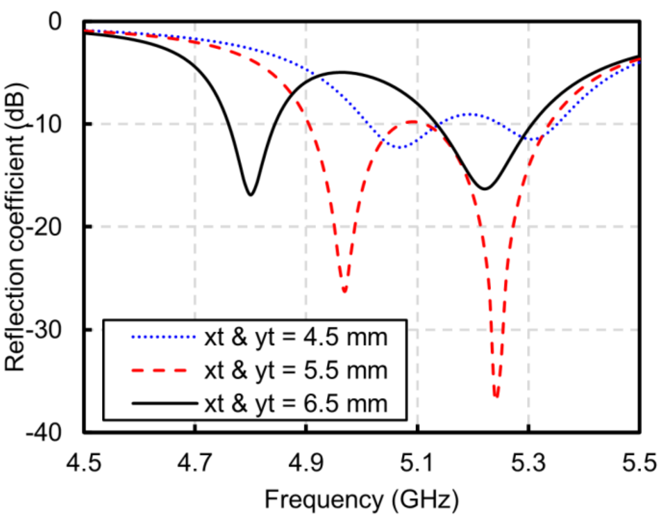
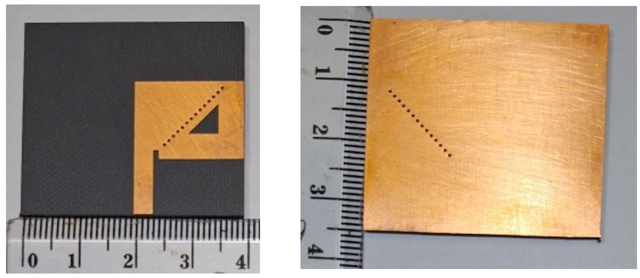


Fig. 9. Study parametric of *xt* and *yt* variables.

III. Result and Discussion

A. *Antenna Fabrication*

The proposed antenna design is fabricated by using a photo etching process as shown in Fig. 10. The photo etching process, also known as photochemical machining or chemical milling, is a manufacturing method used to create intricate metal components with high precision. The metal sheet is immersed in an etchant solution, which chemically removes the exposed metal. The photoresist protects the areas where the metal should remain. The etching process creates the desired pattern or features on the metal.



(a) (b)

Fig. 10. Fabrication of the proposed antenna: (a) top view, (b) bottom view.

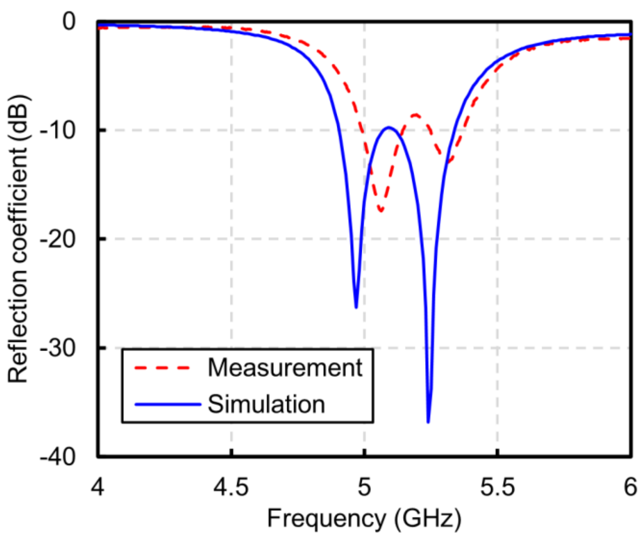


Fig. 11. Reflection coefficient comparison between simulation and measurement.

Fig. 12 shows the measurement of the proposed antenna. The measurement has dual-band frequencies because the reflection coefficient separator between two resonant frequencies becomes higher than the reflection coefficient simulation. It can be caused by friction fabrication.

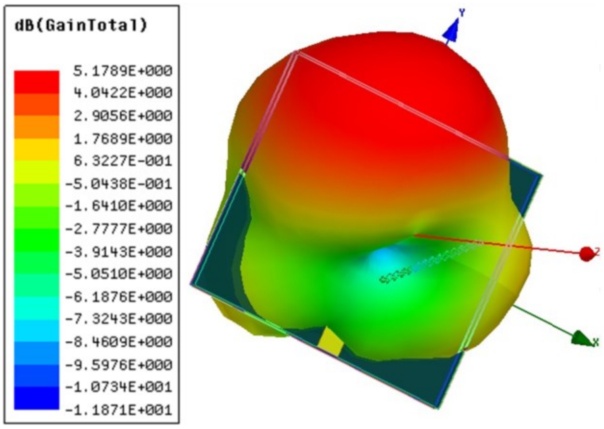
B. *Radiation Pattern Antenna*

Fig. 12 shows the radiation patterns simulation on 4.97 GHz and 5.24 GHz. The proposed antenna has a 5.18 dB and 7.15 dB gain total antenna for 4.97 GHz and 5.24 GHz. The proposed antenna has unidirectional and omnidirectional radiation patterns. The proposed antenna has a good radiation pattern on 5.24 GHz than 4.97 GHz.

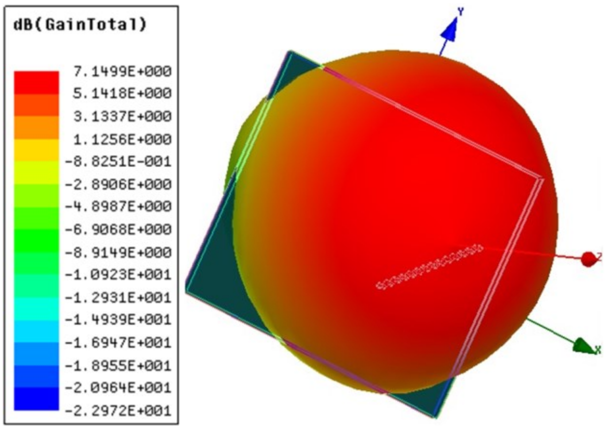
Table II shows the comparison with previous literature. It can be seen that the proposed antenna has higher fractional bandwidth simulation results than others previous research.

TABLE II
COMPARISON WITH PREVIOUS LITERATURE

References	Area (mm^2)	Substrate	Height (mm)	Bandwidth (MHz)	Frequency center (GHz)	Fractional Bandwidth (%)
[8]	3217	Polyester taffeta	3.7	107	2.4	4.46
[9]	1927	RO 5880	1.575	342	5.8	5.9
[10]	1600	F4B2	3	60	3.5	1.71
[18]	382	RO 5880	0.5	630	10	6.3
[20]	2500	F4B2	3	150	3.5	4.29
This work	1400	RO 5880	1.575	440	5.12	8.6



(a)



(b)

Fig. 12. Radiation pattern simulations on (a) 4.97 GHz, (b) 5.24 GHz.

CONCLUSION

Bandwidth Enhancement for QMSIW antenna by using dual cavity and triangle slot has been proposed, fabricated, and measured. The proposed antenna results in an 8.6 fractional bandwidth simulation that is proven by the measurement result. The proposed antenna was resonant on 4.9 - 5.34 GHz. The higher fractional bandwidth is achieved by a combination of two TE_{101} modes that are generated by dual cavities. Dual cavities consist of the inner and the outer cavities. The miniaturized and bandwidth enhancement is achieved in the proposed antenna because of QMISW structure.

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