PERFORMANCE ANALYSIS OF A COMPACT ULTRA-WIDEBAND PATCH ANTENNA USING VARIOUS SLOTS AND NOTCHES FOR KU AND K BAND APPLICATION

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Abstract: In this paper, a compact-sized microstrip patch antenna of dimension 12×12×1.57 mm^3 is presented for the Ku and K band applications. Five slots along with notch, and defective ground are used to enhance the performance of the microstrip patch antenna by changing the current distribution in the radiating patch. The effect of every slot and notch is analyzed in terms of bandwidth, % bandwidth, return loss, and peak gain. The analysis is verified using the results of reflection coefficient, gain, radiation efficiency, etc. The proposed antenna work on two frequencies ranging from (15.9–16.6) GHz and (18.5–24.5) GHz with impedance bandwidth of 4.3 % and 27.9 % respectively. The proposed antenna having 11 dBi gain is applicable for satellite communication, 5G application, and radar applications. The modeling and simulation of microstrip patch antenna are performed on Ansoft HFSS software and measurement of the fabricated antenna is done by VNAN5247A.
Keywords*:* UWB patch antenna, the effect of slots and notches, returnloss, gain, radiation efficiency, group delay, etc.

1. Introduction

Microstrip patch antennas have provided many advances in the advancement of wireless communication systems. Its salient features such as planar configuration, lightweight, low profile, low cost, and easy operation make it a suitable candidate for wireless communication systems [1]. Antennas with multiple operating bands are a new trend. Researchers are focusing on microstrip patch antennas with dual-band [2,3], triple-band [4], quad-band [5], pentaband [6], hexa-band [7], etc. A single antenna with multiple bands can be useful for many applications. Both the implementation cost and the area occupied by that antenna would be low. Currently, researchers are focusing on the smaller-sized antenna with multiple bands. A 20 mm × 15 mm slotted patch antenna displays impedance bandwidths of 12.26 % (14.3 -16.2) GHz, 8.24% (17.4-18.9) GHz, and (3.08 %) (19.3-19.8) GHz. Average gains of 5.6 dBi, 3.5 dBi, and 3.1 dBi have been measured on the first, second, and third bands, respectively. Radiation efficiencies of 80.3%, 81.9%, and 82.5% have been simulated at three resonant frequencies of 15.15 GHz, 18.2 GHz, and 19.5 GHz, respectively [8]. A rectangular slotted microstrip planar antenna is proposed for Ku/K band satellite applications. The radiation patch of the antenna occupies an area of 17 × 17 mm^2 and is fabricated on a bioplastic composite material substrate filled with 1.0 mm-thick ceramics with a dielectric constant (εr) of 10. The antenna has a low resonant mode impedance bandwidth of 18.4% (11.67–14.05) GHz and 8.2% (18.19–19.75) GHz for the S11 <-10 dB with an upper resonance mode bandwidth centered at 12.94 GHz and 19.04GHz, respectively. The antenna prototype achieved a

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maximum gain of 3.1 dBi and 4.13 dBi, with average radiative efficiencies of 75.3% and 86.4% for the lower band and upper band, respectively [9]. The S-shaped slotted patch antenna for Ku band applications is measured to have a -10 dB return loss bandwidth from 15.35 GHz-19.65 GHz (25.59%), with a gain of 6.2 dBi at the resonant frequency 16.8 GHz [10].The antenna achieved 1380 MHz bandwidth. The maximum gain of 7.8 dBi and 89.97% average efficiency within the operating band ensure the suitability of the proposed antenna for Ku band applications from 17.15 GHz-18.53 GHz (7.73%) [11]. A dual-polarized microstrip patch antenna is proposed for Ku-band applications. The overall size of the antenna is (15×15) mm^2. The antenna's impedance bandwidth is 950 MHz (7.76%). It also achieves stable radiation performance with a maximum gain of 7.6 dBi [12].

Researchers and scientists are always in favor of achieving higher gain and bandwidth. They use various methods for the improvement of these two important features like gap coupling, parasitic patch, defected ground, EBG (electromagnetic band gap structure), stacking, MIMO, metamaterial, etc. in which slot utilization is the simplest and most confirmed method to improve bandwidth and gain. In this paper, slots are used to improve gain and bandwidth. The comparative details of the proposed antennas are shown in Table 1. It can be confirmed from the table that the proposed antenna has the smallest area, the highest gain, and larger bandwidth among all the reported antennas from ref [8–12].Large-bandwidth microstrip patch antenna at high frequency such as X/Ku/K is in high demand. UWB (ultrawideband) antennasare becoming popular in advanced communication systems since their adaptation by Federal Communication Commission (FCC) in 2002. According to FCC, an intentional radiator (antenna), at any point in time,has a fractional bandwidth equal to or greater than 0.20 or has a UWB bandwidth equal to or greater than 500 MHz, regardless of the fractional bandwidth[13,14,15].A compact UWB patch antenna with defected ground structure for Ku/K band applications is presented in ref [16]. A slotted circular ultrawideband (UWB) microstrip patch antenna has been reported in ref [17]. It operates in the 4.0-40 GHz range. This antenna can be used in UWB communications with C-band, X-band, Ku-band, Ka-band, WLAN, and future wireless applications [16]. A compact ultra-wideband antenna structure with defected ground is presented in ref [17]. This design has the capability to operate between 1.5 GHz and 10.75 GHz with four notch frequencies [18]

Table. 1 Comparative description of proposed patch antenna

Ref.	Dimension of Antenna (L×W)mm^2	Dielectric constant, εr	Patch Area mm^2	Resonant Frequency (GHz)	Frequency Band (GHz)	BW GHz	Gain (dBi)
8	20×15	4.6	300	15.15 18.2	14.3-16.2 17.4-18.9	1.9 1.5	5.6 3.5

				19.5	19.3-19.8	0.5	3.1
9	17×17	10.0	289	12.94 19.04	11.67- 14.05 18.19- 19.75	2.38 1.56	3.1 4.13
10	20×14	4.6	280	16.8	15.35- 19.65	4.3	6.2
11	20×14	4.6	280	17.75	17.15- 18.53	1.38	7.8
12	15×15	2.2	212.5	12.2	11.76- 12.71	0.95	7.6
Prop.	12×12	2.2	144	16.5 22.2	16.0 - 17.4 18.8-25.4	1.4 6.6	11

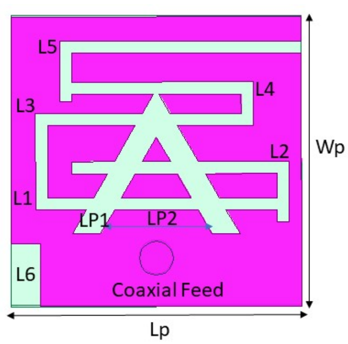
The work has reached saturation in the L, S, C, and X bands. This is why researchers have shifted their focus from the lower to the higher bands. Microstrip patch antenna with optimal structure with high gain and bandwidth is still a struggle for researchers in each operating band [19–28]. An ultra-compact triple band antenna for X/Ku/K band applications is presented in ref [29]. A UWB operating at circular microstrip antennas (2.1-38.6 GHz) is presented in [30]. A compact flower slotted antenna (FSA) for dual-band terminated ultrawideband (UWB) integrated with Ku band applications is presented in ref. [31] Antennas operating in Ku-K band applications can be integrated into many applications such as mobile 5G services, mobile satellite services (MSS), broadcast satellite services (BSS), fixed satellite services (FSS) and radar applications. . , Examples are vehicle monitoring and tracking, weather forecasting, portable satellite broadcasting, and aeronautical/marine navigation [32]. Antennas with compact size, low loss, high bandwidth and gain are still essential for modern communication systems. Many antennas are available on epoxy FR-4 (high lossy) for K and Ku band applications.

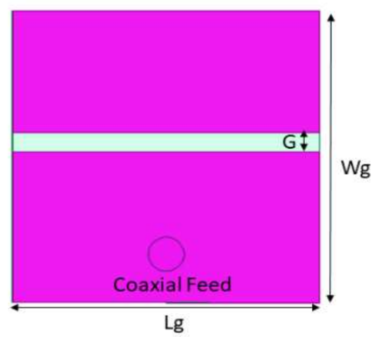
In this study,we propose acompactmicrostrip patch antenna with high bandwidth and gain along with low loss (due to Rogers Duroid 5880 Tm)(c.f. table 1).The evolution of the antenna design is presented in section 2. The antenna was designed and simulated using the Ansoft high-frequency structure stimulator and then the prototype has been manufactured in the laboratory. Reflection coefficient, gain and radiation pattern measurements are performed using the Vector Network Analyzer N5247A. The designed antenna resonates in the range of

Ku and K band frequencies (16–17.4) GHz and (18.8–25.4) GHz. The results and discussion are presented in section 3. The conclusion is presented in section 4.

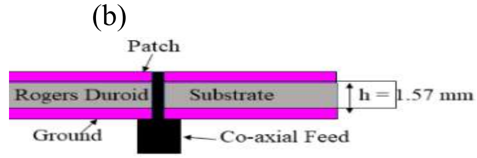
2. Evolution of Antenna Design

Compared to conventional rectangular patch antennas, slot-loaded antennas provide better performance as described in [33–34]. The size and shape of the slot also affect the performance of the microstrip patch antenna. V-slot provides better bandwidth than using U-slot [35]. Hence proposed microstrip patch antenna started with V-slot. Figure 1(a,b,c) shows the proposed antenna patch,ground, and side view respectively. The proposed antenna is designed at 12×12 $mm^2$with Rogers Duroid 5880TM substrate thickness h = 1.57 mm. The antenna is fed by a co-axial feed line at position (4,0 mm). Parametric analysis was performed before obtaining the antenna with optimum size. Here parametric analysis of antenna 4 and Feed position is shown to understand the effect of slots on the performance of microstrip patch antenna.

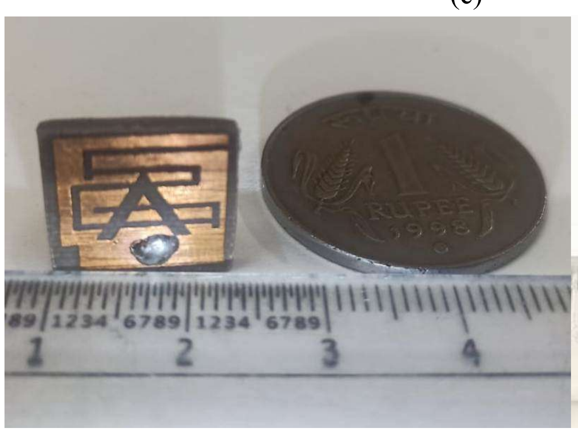


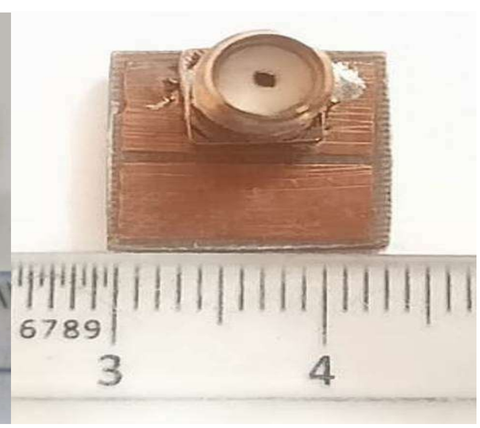


(a) (b)



(c)



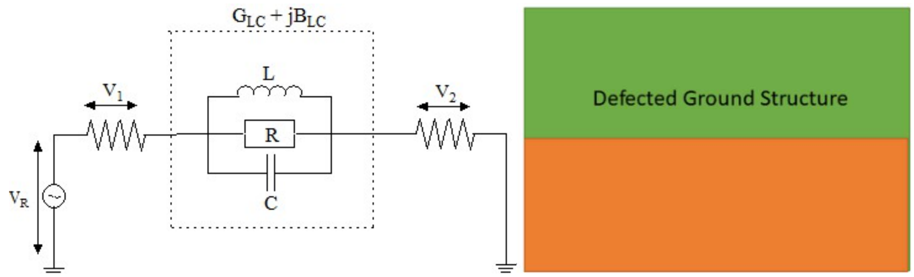


(d) (e)

Fig. 1. Simulated diagram of the proposed antenna (a) patch view (b) ground view (c) side view(d) fabricated antenna top view(e) fabricated antenna ground view

Effect of DGS

The antenna radiation and bandwidth of an antenna can be improved by defected ground structure.The defected ground structure increases inductance value and reduce capacitance valueand hence change the current path and electrical element of equivalent circuit of microstrip patch antenna. The equivalent circuit,a sample of defected ground structure and the equation that results in large bandwidth as shown in fig.1(f).



(f)

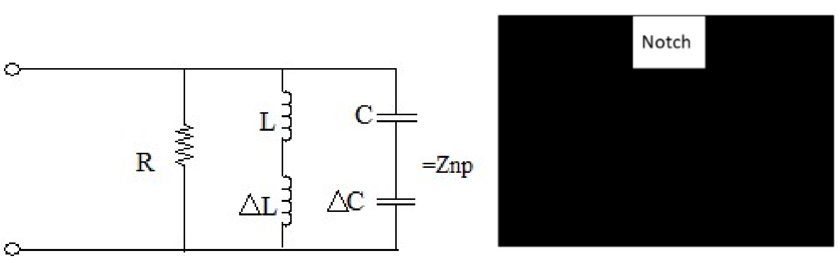
$$C = \frac{\omega_c}{2Z(\omega_0^2 - \omega_c^2)}$$

$$L = 1/4\pi^2 f_0^2 C$$

$$R(\omega) = \frac{2Z_\circ}{\sqrt{\frac{1}{|S_{11}(\omega)|} - \left(2Z_0\left(\omega C - \frac{1}{\omega L}\right)\right)^2 - 1}}$$

Effect of notch on microstrip antenna

Notches when introduced on a patch create multiple resonances and change the flow of current. Initially the current length of the patch is responsible for the flow of current and generates resonance, when notch is etched on the radiating patch the second resonance frequency is generated due to current length as the current flow in two different ways around the patch as well as around the notches. This phenomenon replaces capacitance and inductance of equivalent circuit with series of inductance and capacitance according to [36] as shown in Fig 1(g).



Znp = (1/1/R) + (1/jwL1) + (jwC1)

Where L1 = ΔL + L

C1 = CΔC/C + ΔC

(g)

Effect of slot on antenna

Patch of antenna is analyzed using the duality relationship between slot and antenna .the introduction of slot led parallel impedance to the impedance of the antenna. Impedance of the path antenna is dependent on resultant of resistance and capacitance of the patch antenna. According to [37] as shown in fig.1(h).

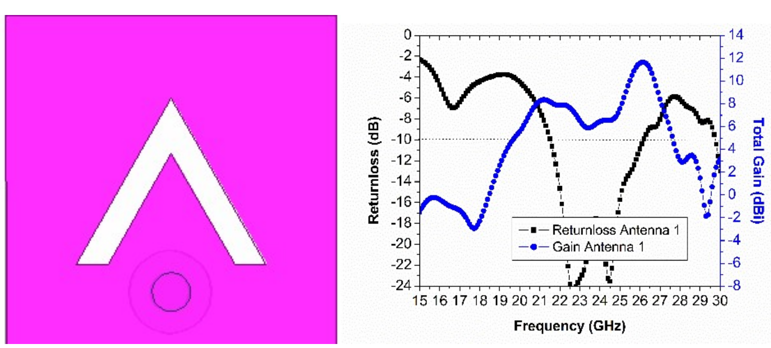
$$(Z_s = R_r + jX_c)$$

(h)

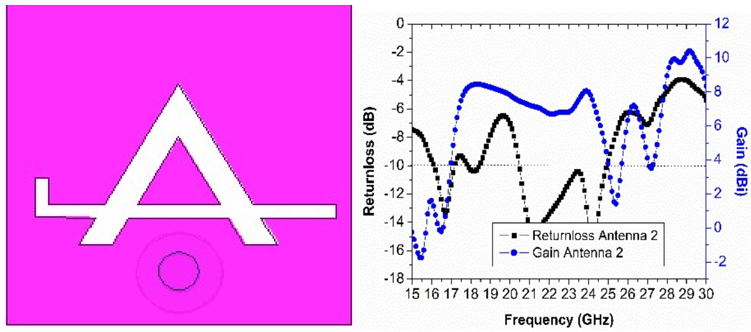
Fig. 1.Operating Mechanism Using (f) Defected Ground Structure (g) Notch (h) Slot

The simulatedproposed antenna with patch,ground, and side view is shown in Fig.1(a-c).The fabricated proposed antenna top view (patch), ground view along with reflection coefficient and gain (measured/simulated) are shown in Fig.1(d-f).The proposed antenna is designed using several intermediate steps to achieve ultra-wideband with high gain in the Ku and K band range. The proposed antenna is developed in eight simple steps. Five tilted L-shape slots (L1-L5) and a rectangular notch(L6) are loaded onto the antenna's patch, while a rectangular slot (G) of dimension (0.8×12) mm^2 is used in the antenna's ground plane.The growth and plot from Antenna-1 to Antenna-8 are shown in Fig.2(a–h).All Antennas (1-8) simulated returnloss and total gain are shown in Fig. 2(i-j) respectively.

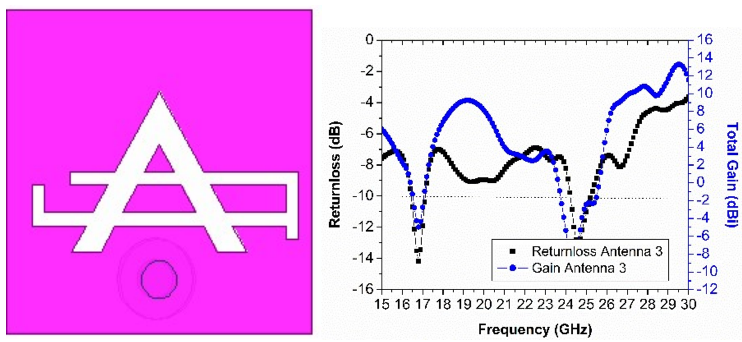
The design of the proposed antenna is initiated with an inverted V-shaped slot in Antenna-1 which resonates in a single band with a bandwidth of 4.6 GHz and an impedance bandwidth of 19.3% (21.5 - 26.1GHz). Peak gain is 12 dBi. But the aimis to find the antenna that resonates for the ultrawideband.A tilted L-shaped slot (L1) is loaded onto Antenna-1 for receiving Antenna-2, which resonates on two bands(16.0 - 17.0) GHz and (20.4 - 24.8) GHz with the impedance bandwidth of 6.0% and 19.4% respectively but has a 3 dBi reduction in gain compared to Antenna-1.Now the L-shaped slot (L2) is loaded onto antenna-1 to form antenna-3, but it shows negative gain in the resonatingband.



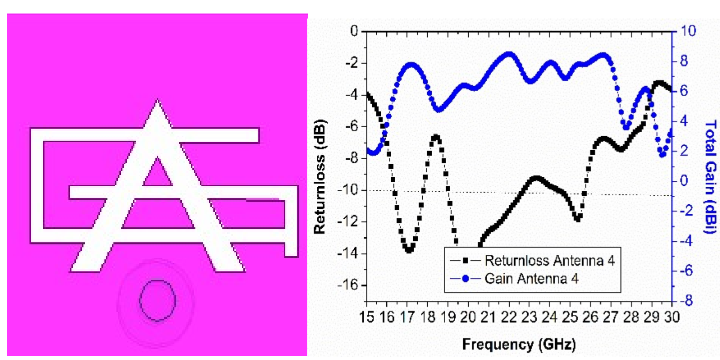
(a) Antenna-1 Simulated returnloss and total gain



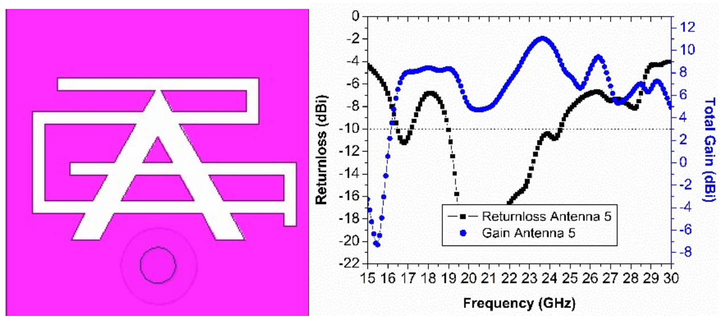
(b) Antenna-2 Simulated returnloss and total gain



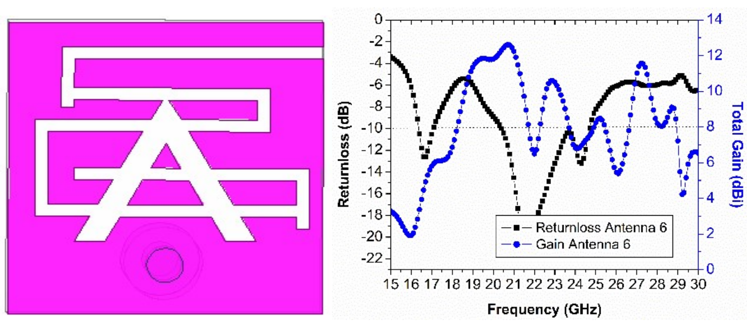
(c) Antenna-3 Simulated returnloss and total gain



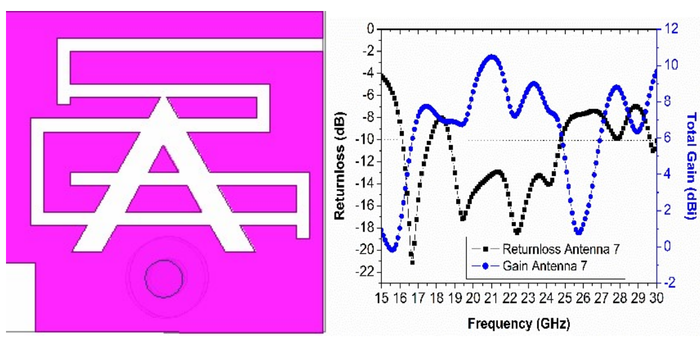
(d)Antenna-4 Simulated returnloss and total gain



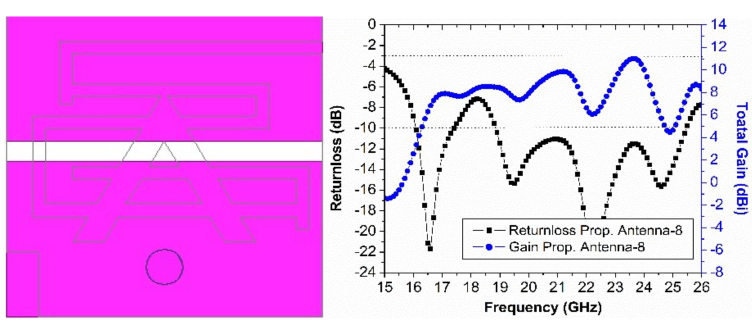
(e) Antenna-5 Simulated returnloss and total gain



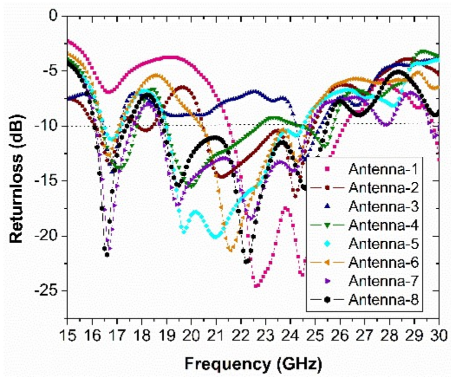
(f)Antenna-6 Simulated returnloss and total gain

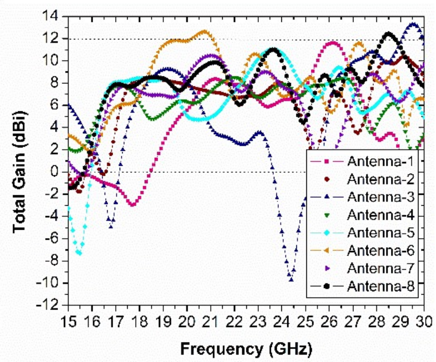


(g) Antenna-7 Simulated returnloss and total gain



(h) Antenna-8 Simulated returnloss and total gain





(i) Antenna 1-8 Simulated Returnloss(j) Antenna 1-8 Simulated Total Gain

Fig. 2. View of different antenna Geometries A1-A8,(a)Antenna-1 (b)Antenna-2 (c)Antenna-3 (d) Antenna-4
(e) Antenna-5 (f) Antenna-6(g) Antenna-7 (h)Antenna-8 (i) Antenna 1-8 simulated returnloss (j) Antenna 1-8 simulated total gain

Table 2. Proposed Antenna Parameters

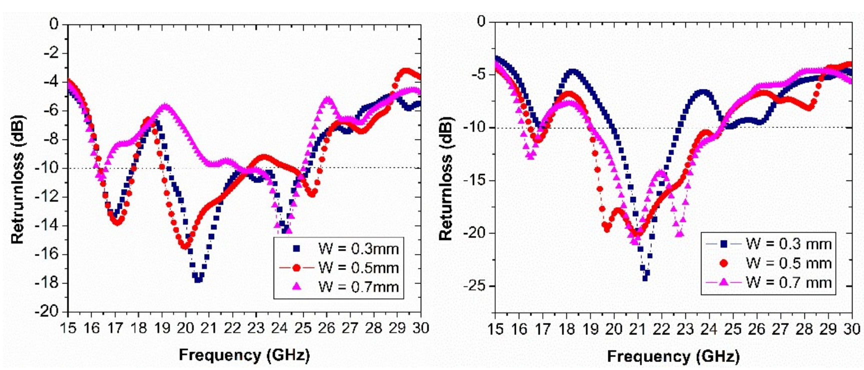
L1	L2	L3	L4	L5	L6
(10×0.5)+(2.3 ×0.5)	(7.5×0.5)+(1.6 ×0.5)	(8.8×0.5)+(3.4 ×0.5)	(10×0.5)+(2.5 ×0.5)	(9×0.5)+(2.9 ×1.3)	(1.2 × 2.6)
G	**LP1,LP2**	**L_p, W_p**	**L_g,W_g**	**Feed position (x, y)**	**Substrate height**
(0.8 ×12)	2 , 6	12	1	(4, 0)	1.57

*All the dimensions mentioned in table 2 are in millimeters (mm)

Table 3. Summarized All Antenna Performance

Antenna	Frequency range (GHz)	B.W. (GHz)	% B.W.	Maximum Return Loss (-ve dB)	Peak Gain (dBi)
Antenna 1	21.5 - 26.1	4.6	19.3	-24.6	11.6

Antenna 2	16.0 - 17.0 20.4 - 24.8	1.0 4.4	6.0 19.4	-12.82 -23.3	8.0
Antenna 3	16.4 – 17.1 24.2 – 25.2	0.7 1.0	4.2 4.0	-14.0 -12.6	(-ve)9.6
Antenna 4	16.3 -17.8 19 - 22.6 24.5 – 25.7	1.5 3.6 1.2	8.8 17.3 4.7	-13.7 -15.5 -11.8	8.5
Antenna 5	16.5 - 17.2 19.0 – 24.4	0.7 5.4	4.2 24.8	-11.2 -20.0	11.0
Antenna 6	16.4- 17.0 20.4 -24.7	0.7 4.3	4.2 19.0	-12.5 -21.3	12.6
Antenna 7	16.0-17.6 18.7-24.7	1.6 6.0	9.5 27.6	-21 -18.3	10.5
Antenna 8	16.0-17.4 18.8-25.5	1.4 6.7	8.4 30	-22.0 -22.2	7.9 11.2



(a) (b)

Fig. 3 (a) Parametric Analysis of Antenna-4 (b) Parametric Analysis of Antenna-5

In the next attempt, Antenna-4 is designed using slot (L3) to increase bandwidth and gain. The gain in antenna 4 is greater than the negative gain in antenna 3. Peak gain is up to 8.5 dBi. In addition, Antenna-4 is resonating in three bands (16.3 -17.8) GHz, (19 - 22.6) GHz, and (24.5 - 25.7) GHz with impedance bandwidths of 8.8%, 17.3%, and 4.7%, respectively. But none of

the bands reach UWB (Ultra Wide Band). In addition, antenna-5 is designed by loading an L-shaped slot (L4) with impedance bandwidth in two bands (16.4–17.2) GHz and (18.6–24.5) GHz with 4.7% and 27.3%, respectively, and the peak gain is 11 dBi. Although we get ultrawideband in Antenna-5 (18.6-24.5) GHz. But still, more efforts tried to increase the bandwidth.
Slot L5 is engraved to make Antenna-6. This antenna resonates with bandwidths (16.3–17.0) GHz and (20.4–24.7) GHz with impedance bandwidths of 4.2% and 19.0%, respectively. Although Antenna 6 shows a peak gain of 12.6 dBi, still is not obtained. Antenna-7 slot L6 is used. Antenna-7 resonate with two bands (16.0–17.6) GHz and (18.7–24.7) GHz with resonant impedance bandwidth of 9.5% and 27.6%, respectively. Defected Ground Structure (G) is used in Antenna-8. It resonates with two bands (16.0–17.4) GHz and (18.8–25.5) GHz with impedance bandwidths of 8.4% and 30%, respectively. The peak gain shown by Antenna-8 in the bands (16–17.4) GHz and (18.8–25.4) GHz is 7.9 dBi and 11.2 dBi, respectively. The design parameters of the proposed antenna are described in Table 2. Antenna 1-8 development focused on high performance and miniatrirised patch area.

Adding the number of slots to the radiating patch increases the antenna resistance which increases the current distribution and further improves the radiation in the antenna. Parametric analysis of all slots was performed to find antennas with optimal dimensions. For simplification, Fig.3 shows the parametric analysis of slots L3 and L4 by varying the width of the slots (from 0.3 mm to 0.7 mm) of antenna-4 and antenna-5, respectively. Slot width 0.5mm showing improved bandwidth. Therefore the slot width is chosen at 0.5 mm. Antenna -8 is UWB and is the smallest in patch size (maximum slots present) among all other designed and simulated antennas. Hence it has been chosen as the proposed antenna. The conventional formula is used to find out the antenna parameters according to the operating band. But these antennas usually offer low bandwidth. Various methods have been described in the literature to increase bandwidth and gain. We have implemented a trial and error method to increase bandwidth and gain. Using slots is the simplest and most definite way to increase gain and bandwidth. Table 3 describes the frequency range, bandwidth (BW), impedance bandwidth (%BW), return loss, and peak gain of all designed and simulated antennas.

3.Results and Discussion

Simulated and measured results of the proposed antennas are shown and discussed in this section. The proposed antenna design is simulated on High Frequency Structure Simulator (HFSS) and the fabricated antenna is measured by VNA model N5247A which is shown in Fig. 4. The simulated and measured reflection coefficient of the proposed antenna-8 are shown in Fig. 5.Bandwidths of 0.7 GHz (15.9–16.6 GHz) and 6.0 GHz (18.5–24.5 GHz) are achieved with impedance bandwidth of 4.3% and 27.9% as shown in Figure 5.However, the simulated returnloss and Gain results of the proposed antenna do not match exactly. There is some difference between the simulated and measured results. Variation in results is due to several factors like manufacturing error, insertion loss, loss of SMA connector, and external disturbances are the main reasons. However, the Gain is above zero throughout the operating frequency band and its peak gain is 10dBi in (18.5-24.5) GHz band (c.f. Fig 6).Simulated radiation efficiency varies from 74 % to 98% through the operating frequency range. The measured radiation efficiency deviates slightly from the simulated radiation efficiency and ranges from 74 % to 97 % over the entire operating band. Group delay varies between -1ns to 1 ns indicating that interference between the signal is in the acceptable range throughout the operating frequency range. Simulated along with measured radiation efficiency and group delay of proposed antenna Antenna-8are shown in Fig.7 (a) and Fig. 7(b) respectively.

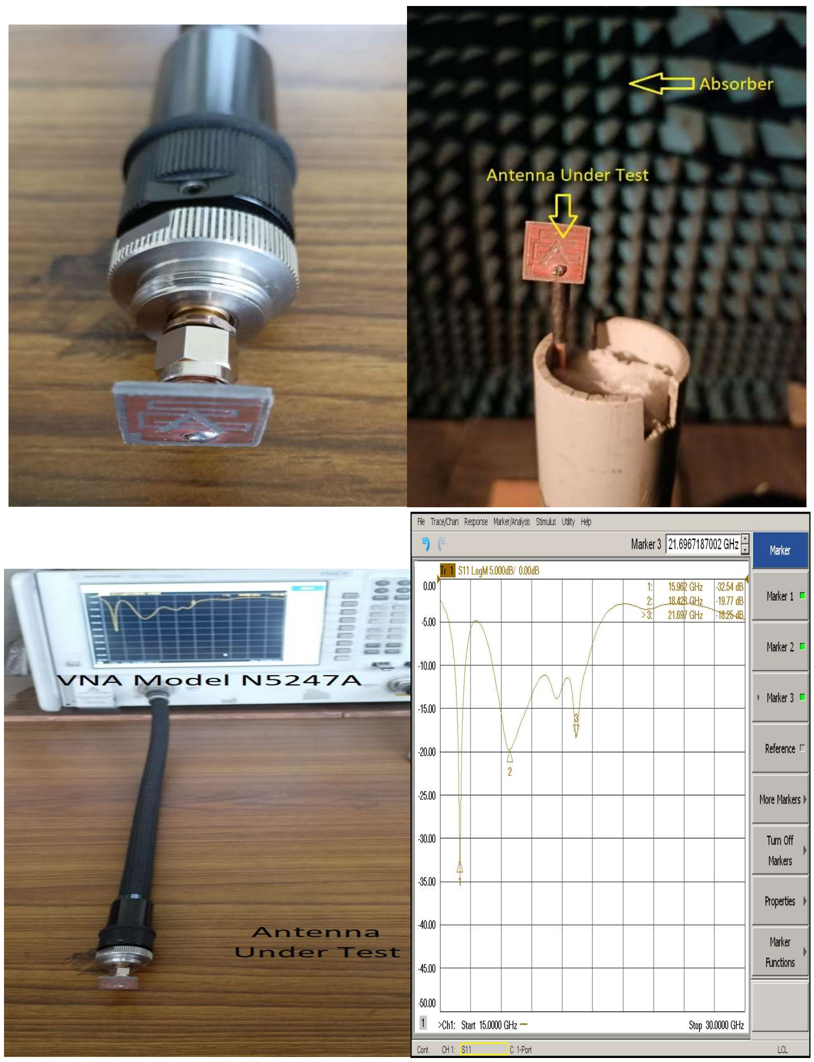


Fig. 4. Photograph proposed Antenna-8duringMeasurement

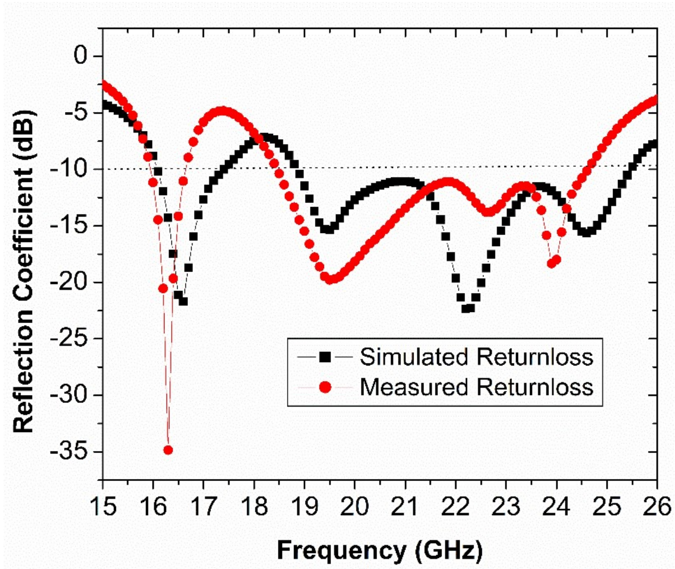


Fig. 5. Reflection coefficient Simulated and measured proposed Antenna-8 with the variation of frequency

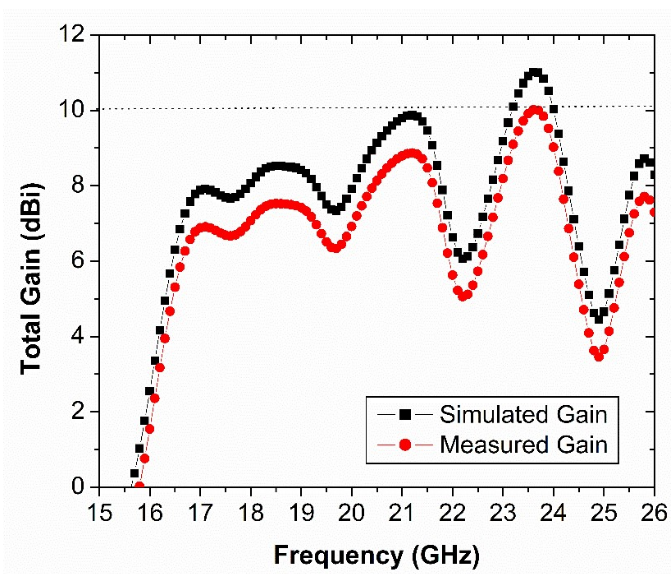


Fig. 6.Gain Simulated and Measured proposed Antenna-8 with the variation of frequency

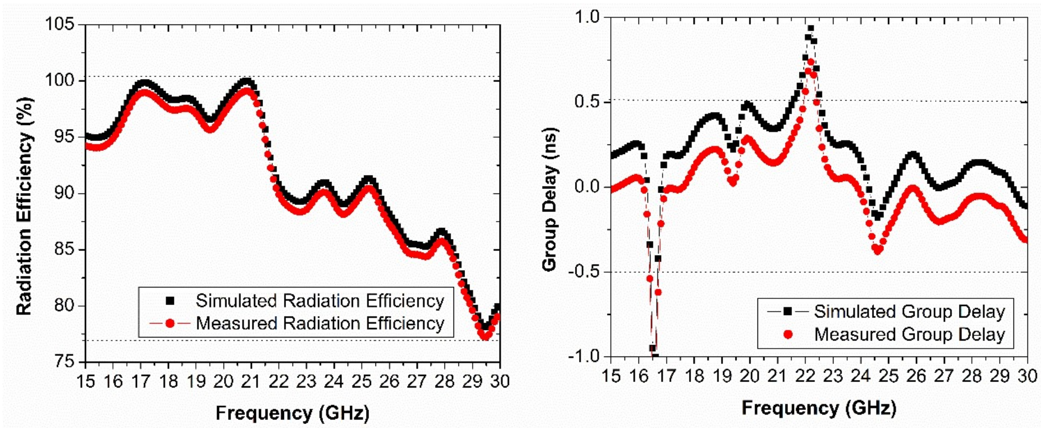
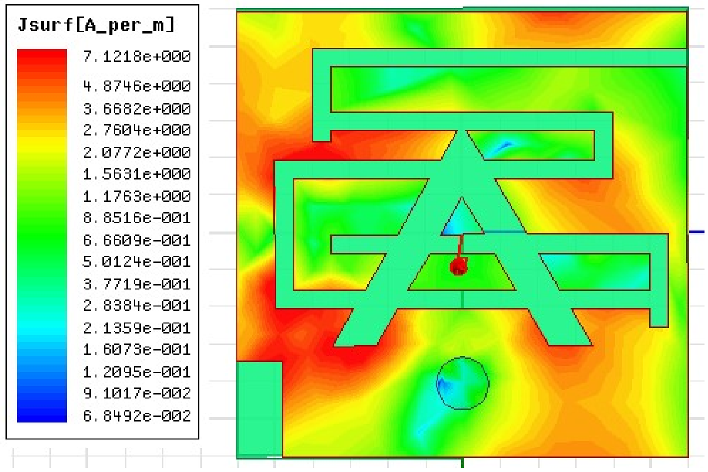


Fig. 7. (a) Radiation Efficiency Simulated and Measured (b) Group DelaySimulated and Measured of proposed Antenna-8 with the variation of frequency

Antenna-1 was excited with coaxial feed, surface current distribution was prominent at the coaxial feed and around the inverted V slot which makes the structure resonant for (21.5 - 26.1) GHz. The maximum current distribution is observed near the port. Other slots are used to shift the operating band towards the lower frequency which as a consequence makes the current to be distributed uniformly on the patch. The surface current distribution of the proposed Antenna-8 is shown in fig.8 at frequencies 16.0 GHz, 18.4 GHz, and 21.6 respectively. The value of surface current distribution at 16.0 GHz,18.4 GHz, and 21.6 GHz are 71.2 A/m, 61.5 A/m, 60.5 A/m, and 61.5 A/m respectively. The 3-D simulated gain plot is shown in fig.9. The value of gain at 16.0 GHz,18.4 GHz, and 21.6 GHz are 8.7 dBi,9.6 dBi, and 11.8 dBi respectively. Simulated and measured co and cross radiation pattern of the proposed antenna in both the E-plane and the H-plane for 16 GHz, 18.4GHz, and 21.6GHz frequencies shown in fig 10.The far-field radiation patterns of the fabricated antenna are measured in the anechoic chamber when the elevation axis corresponds to the polar axis (θ = 0°) for the coordinate system of the antenna. Consequently, the azimuth drive created consistent cuts. The fixed reference antenna was a broadband horn antenna.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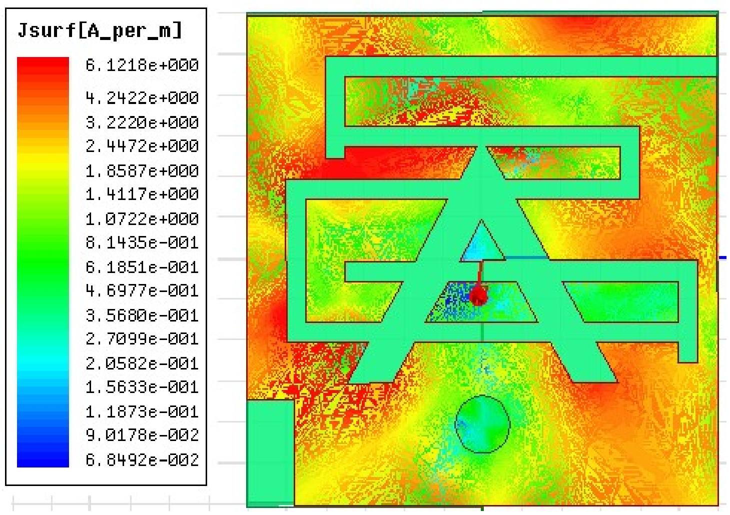
8.8516e-001
6.6609e-001
5.0124e-001
3.7719e-001
2.8384e-001
2.1359e-001
1.6073e-001
1.2095e-001
9.1017e-002
6.8492e-002

(a)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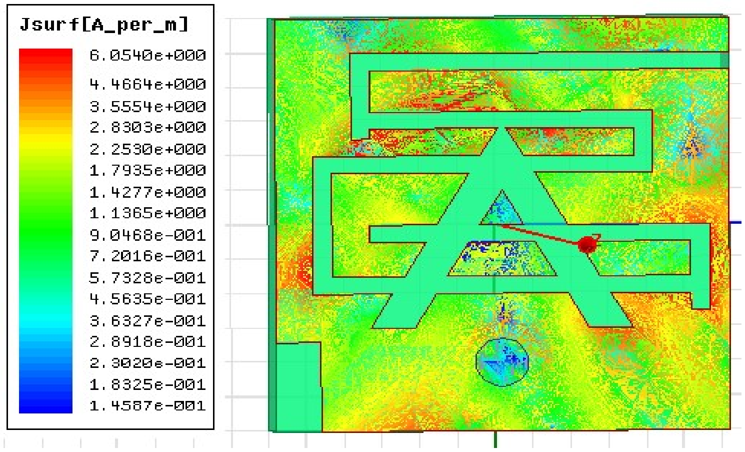
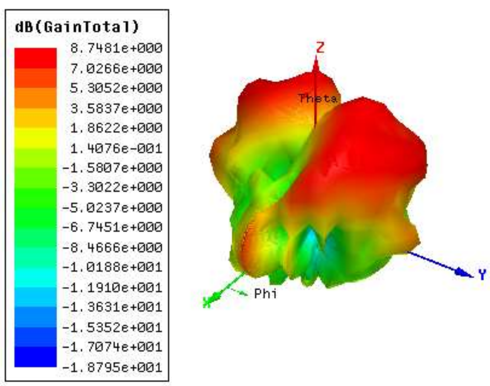
(b)

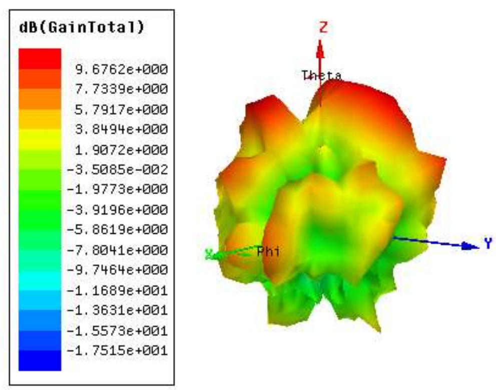


(c)

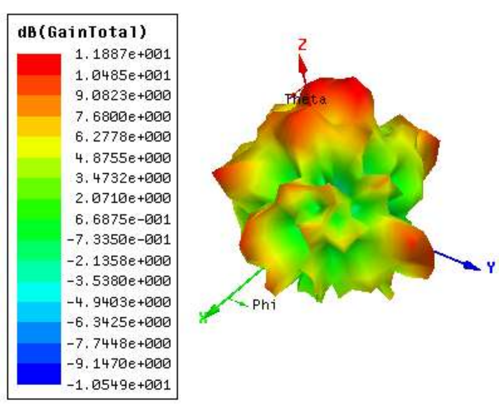
Fig. 8. Surface current distribution on patch of proposed Antenna-8 at (a) 16.0 GHz (b) 18.4 GHz (c) 21.6 GHz



(a)

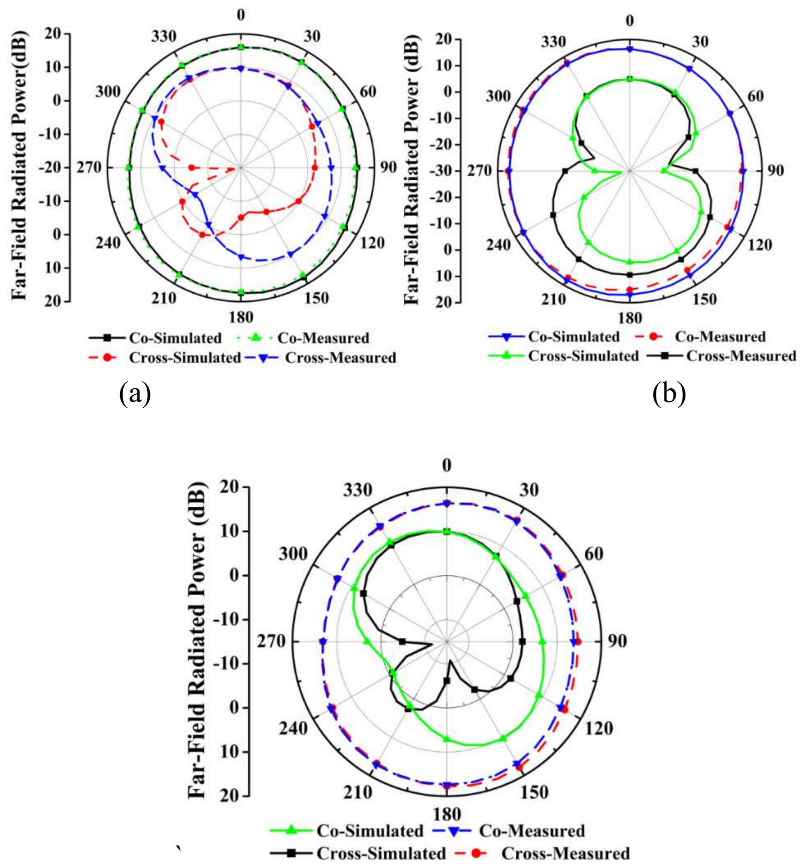


(b)



(c)

Fig. 10. 3D Gain plot of proposed Antenna-8 at (a) 16.0 GHz (b) 18.4 GHz (a) 21.6 GHz



(a) (b)

(c)

Fig. 10. Radiation pattern of proposed Antenna-8 at (a) 16.0 GHz (b) 18.4 GHz (b) 21.6 GHz

4. Conclusion

In this paper, we have designed a UWB microstrip patch antenna using multiple slots and notches. In this study, minute changes in the radiating patch are shown by inserting slots and notches into the antenna and viewed in terms of bandwidth and gain. The proposed designed antenna, Antenna-8 which has an impedance bandwidth of 4.3% and 27.9%, as well as with a peak gain of 10dBi is applicable to operate in Ku and Ka-band applications (15.9–16.6) GHz and (18.5-24.5)GHz with a frequency range of GHz. , Radiation efficiency varies from 74% to 97% through the operating frequency range with group delays between -1ns to 1ns. It is the most suitable candidate that can be used for vehicle monitoring/tracking, weather forecasting, portable satellite telecasting, and aeronautical/marine navigation.

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