Dual Band Slotted Ground Microstrip Antenna for Location Tracking Systems

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***Abstract*—Slotted ground microstrip antenna can be devised to radiate electromagnetic waves in the allotted bands for location tracking (LT) applications. The signal is fed through a microstrip feed line towards the centre of the substrate. The rectangular slots placed in the ground plane are carefully designed to propagate linearly polarized signals in two bands viz. 4.66 – 4.77 GHz (the band I) and 6.13 – 6.67 GHz (the band II). The antenna produces a fair gain in both the bands.**

Keywords—microstrip antennas, location tracking, slotted ground

I. Introduction

Ultra wideband (UWB) devices operate in the official band of 3.1 GHz to 10.6 GHz. They enable deep penetration and positioning inspite of multipath effects due to obstacles like furniture, walls etc. These features of UWB technology develop a new category of sensors, termed as location tracking (LT) sensors with diversified applications. Small mobile gadgets, serving as either transmitters or receivers, or both, are fastened with the objects to be tracked, or carried by individuals within the region of observation. A network of fixed equipment around the region to be observed, communicate with the object/person. The 2D/3D location of the object/person can be obtained by assessing the time and angle of arrival of the electromagnetic signal relative to the known reference stations. Generally, the distance between the point under observation and the reference terminal may be up to 200 m, depending on the region to be observed. There are four different categories of LT systems which make use of UWB positioning technologies [1,2]. They are as follows;

1) LT1: intended for general purpose location tracking of people and objects.

2) LT2: particularly used for tracking people and objects in industrial environments where conventional RF and GNSS solutions are inadequate.

3) LAES (Location tracking Application for Emergency Services): for tracking persons working in fire extinguishing operations and other hazardous situations.

4) LTA (Location Tracking and sensor Applications): deployed for automotive and transportation applications.

The frequencies allotted for various LT systems shown in Table 1. reveals that these frequencies are focused in two bands viz. 3.1 – 4.8 GHz and 6 – 9 GHz.

TABLE 1. FREQUENCY BANDS ALLOTTED FOR LT SYSTEMS

Sl. No.	*LT system*	*Allotted frequency band*
1	LT1	6 – 9 GHz
2	LT2	3.4 – 4.8 GHz and 6 – 8.5 GHz
3	LAES	3.1 GHz to 4.8 GHz
4	LTA	3.1 – 4.8 GHz and 6 – 8.5 GHz.

The different techniques and methodologies reported in articles that discuss dual band planar antennas are reviewed and investigated. A radiator consisting of a square and circular ring slots and fed by an L-shaped microstrip line [3], double-slotted rectangular patch and slotted ground [4], U-shaped slot [5], metamaterial-based electromagnetic bandgap [6], slot and spur transmission lines [7] and rectangular split-ring resonators [8] are few of them. Shorted-pin four-element patch antenna array with SRR and metallic via hole on each patch element is treated in [9]. In order to reduce the cross-polarization levels, shorted, centered and offset pins are introduced in [10]. Modified circular-shaped slot antenna with asymmetrical feed line for dual-frequency applications is tried in [11]. A metamaterial-loaded antenna reported in [12] provides wide measured bandwidths. A patch with rectangular spiral and two stubs together with band-stop reflector based on frequency selective surface is illustrated in [13]. Dual band filter antenna with U-shaped and inverted H-shaped slot and fed by microstrip lines having two pairs of symmetrical open stubs are proposed in [14]. Partial ground plane with rectangular slot and T-shaped copper integrated with symmetrical circles on either side of T-shape is dealt in [15].

The desire behind the development of the proposed slotted ground microstrip antenna (SGMA) is that all the reported articles that deal with microstrip antennas for dedicated applications were not associated with developing antenna exclusively usable for the approved band of the location tracking system. In this work, a microstrip feed line and the rectangular-shaped slotted ground is used to radiate two narrow bands in the UWB band that can be used for the said purpose. Since the structure is simple to design and the resonance frequencies are tunable, the proposed antenna can be deployed for LT1, LT2, LAES and LTA systems.

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II. Slot Antenna: Principles and Design

A. *Slot antenna principles*

A slot antenna can be considered as physically complementary to a dipole antenna made of a metal strip and having identical size and shape as that of a slot so that we would get an infinite conducting plane when this slot antenna is superimposed on this complimentary dipole antenna. By applying Babinet's principle and by incorporating the symmetry in Maxwell's equations and perceiving the complementary formation of the two configurations, it can be proved that the fields of a slot antenna and that of a complementary dipole antenna are related to each other [16]

B. *Antenna design*

The proposed slotted ground microstrip antenna (SGMA) is configured to ply in dual bands which are within the officially specified frequency band for location tracking applications. The geometrical layout of the SGMA is shown in Fig. 1. The SGMA comprises of a square-shaped FR4 substrate with dielectric constant $\varepsilon_r = 4.4$, height $h = 1.6$ mm, loss tangent $\tan\delta = 0.02$ and having a dimension of 30×30 mm^2. A microstrip feed line extends towards the centre of the top surface. The positive terminal of the SMA connector is connected to this feed line having an area of 54 mm^2. Ground plane consists of a copper area of the entire substrate with two rectangular parallel slots. These rectangular slots are placed along the *x*-axis, apparently crossing the feed line placed on the other side of the substrate. Moreover, a U-shaped symmetrical cut is given on the upper side of the ground plane. The thickness *t* of the microstrip feed line and ground plane are 0.035 mm.

Initially, the width of the microstrip feed line (w) is designed to match the characteristic impedance of the transmission line (50 Ω) using (1) and (2).

$$\frac{w}{h}=\frac{2}{\pi}\left\{B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1)\right]+0.39-\frac{0.61}{\varepsilon_r}\right\} \quad (1)$$

$$\text{Where } B=\frac{60\,\pi^2}{Z_o\sqrt{\varepsilon_r}} \text{ and } Z_o = \text{Characteristics impedance} \quad (2)$$

Now the length of the two slots $w1$ and $w2$ are designed for resonance frequency 4.7 GHz and 6.3 GHz respectively as follows;

$$\lambda_o=\frac{c}{f} \quad (3)$$

$$\lambda_g=\frac{\lambda_o}{\sqrt{\varepsilon_{eff}}} \quad (4)$$

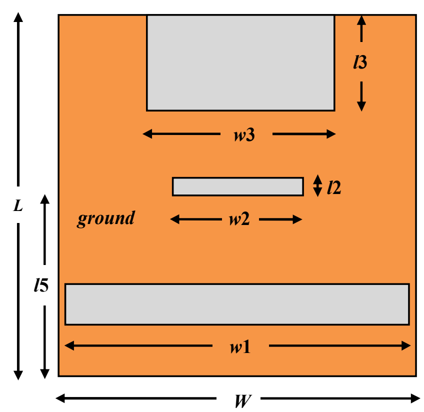
where ε_{eff} is the effective dielectric constant.

$$\varepsilon_{eff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-1/2} \quad (5)$$

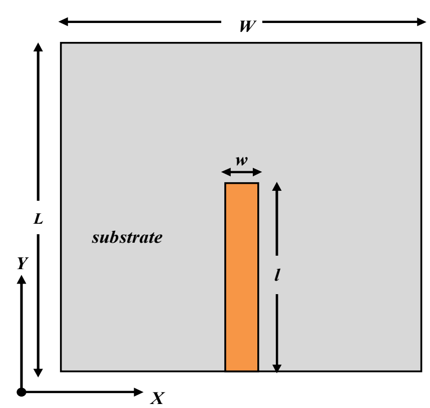
Here λ_{g1} = 35.4 mm and λ_{g2} = 26.9 mm at the resonant frequencies 4.7 GHz and 6.2 GHz respectively. The length of the first slot, $w1$ for 4.7 GHz is 14.2 mm which is equal to $0.4\lambda_{g1}$. Similarly, the length of the second slot, $w2$ for 6.2 GHz is 29.5 mm which is equal to $1.09\lambda_{g2}$. This points to the approximate length of the slot as multiples of $\lambda_g/2$ at both the resonant frequencies. The width of the slots $l1$ and $l2$ are initially taken as 10 % of its length. Later on, the values are varied and optimized to match the impedance.

One of the salient attraction of slotted ground design is that the structure demands very less copper space. The U-shaped cut introduced at the upper part of the ground improves the impedance matching of the antenna. Moreover, the rectangular cut will again reduce the copper area by 19.5 % and will provide better control for tuning the required frequency band. Introduction of this space may push the resonance away from the expected spot on the return loss plot. Hence the placement and dimensions of the slots were modified slightly and optimized accordingly.

The optimized dimensions (in millimeters) of the proposed antenna are shown in Table 2. The structure is very simple to design as it consists of only rectangular shapes and there are only 12 parameters for its design.



(a)

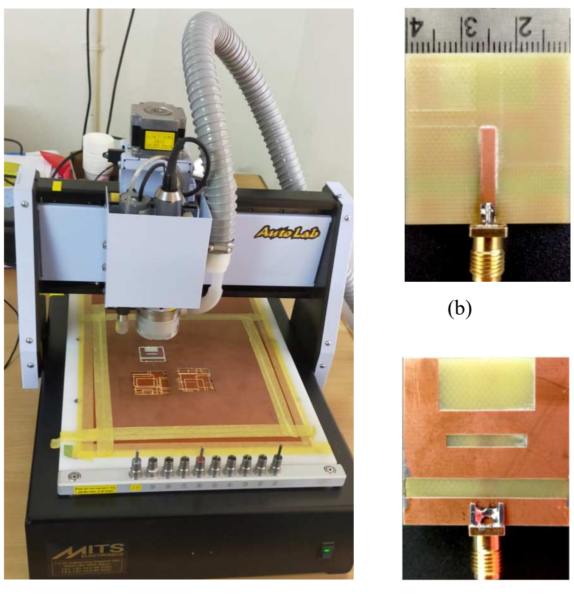


(b)

Fig. 1. SGMA layout a) Top view. b) Bottom view.

TABLE 2. OPTIMIZED DIMENSIONS OF SGMA

Parameter	*value*	*Parameter*	*value*
L	30	*l*2	2
W	30	*w*2	14.2
w	3	*l*3	9.5
l	17	*w*3	17
*l*1	3.2	*l*4	5
*w*1	29.5	*l*5	14



(b) (c)

Fig. 2. a) PCB prototyping machine. b) SGMA top view. c) SGMA bottom view.

III. Results and Discussion

The antenna has been simulated in Microwave CST studio suite software. The antenna parameters like return loss, impedance bandwidth, gain and radiation patterns are analyzed. Moreover, parametric studies are carried out to evaluate the response of the antenna for critical dimensional variables. The antenna is fabricated on the PCB prototyping machine (Model: Auto Lab by MITS Electronics) in the university lab which is shown in Fig. 2(a). The fabricated structure of the antenna is displayed in Fig. 2(b) and Fig. 2(c).

A. Return loss and impedance bandwidth

The power reflected from an antenna is studied by analyzing the values of its return loss. The simulated and the measured return loss plots of SGMA are traced in Fig. 3. The simulated return loss plot in the figure conveys that the antenna radiates in two bands viz. band I (4.66 – 4.78 GHz) and band II (6.01 – 6.65 GHz) resonating at 4.73 GHz and 6.29 GHz with a -10 dB impedance bandwidth of 120 MHz and 640 MHz respectively, which is adequate for location tracking systems. The return loss values at the instant of resonances are -36.6 dB and -37.7 dB. This reflects a good impedance matching within the two desired bands. The antenna provides a fractional bandwidth of 2.54 % and 10.11 % in the band I and band II respectively which is acceptable for narrowband microstrip antennas. The measured values indicate the presence of two bands viz. 4.66 – 4.77 GHz (the band I) and 6.13 – 6.67 GHz (the band II) with a -10 dB impedance bandwidth of 110 MHz and 540 MHz and resonating at 4.71 GHz and 6.42 GHz respectively. This shows a good agreement with the simulated values in the band I except in the value of depth of resonance. Minor discrepancies are seen in the band II. The resonant frequency has been shifted from 6.29 GHz to 6.42 GHz with a shortening of impedance bandwidth from 640 MHz to 540 MHz. These variations may occur due to the fabrication inaccuracies developed in the slot length and systematic errors occurred during measurements.

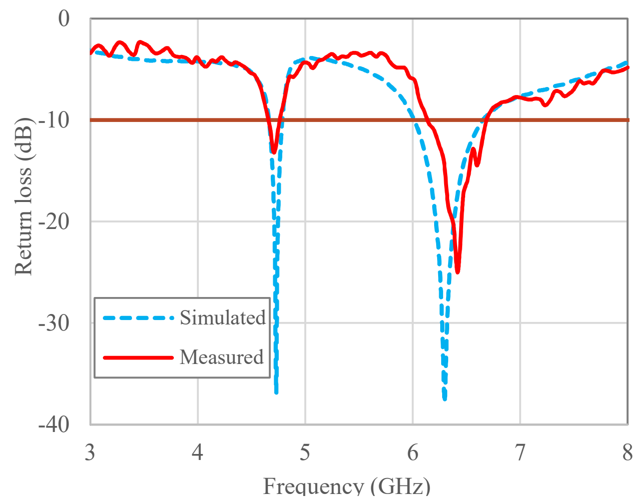
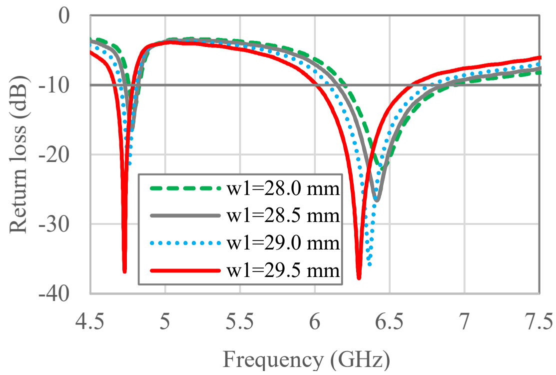


Fig. 3. Simulated and measured return loss plots

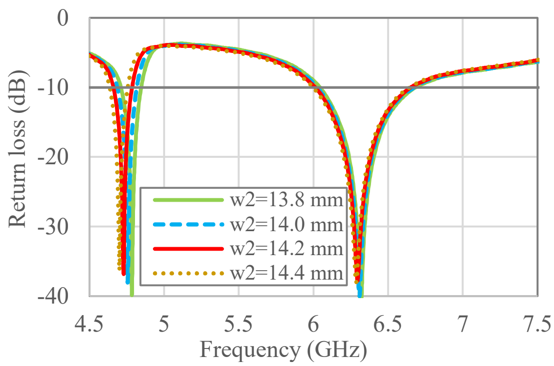
The above mentioned variations will never effect the functioning of the location tracking system as the measured readings are within the acceptable ranges of the permissible band limits.

A parametric analysis has been carried out to determine the effect of critical parameters on the return loss and thereby on the resonance and the impedance bandwidth. A variation on the slot length *w*1 and *w*2 shift the resonant frequency of band II and the band I respectively which is self-explanatory from Fig. 4(a) and 4(b). Increasing the slot length lowers the resonant frequency. Similarly, the slot dimension *l*1 and *l*2 have the role of improving the impedance matching.

Studies on variation in length and width of U-shaped cut are depicted in Fig. 5. (a) and Fig.5. (b). The plots reveal that the dimensions of this rectangular cut can be optimized to improve impedance matching. The position and placement of slot 1 and slot 2 in the *y*-axis have a pivotal role in fixing the passband location for location tracking applications. This is illustrated with the help of Fig. 6. (a) and (b).



(a)



(b)

Fig. 4. a) Effect of variation of slot length *w*1 on the resonant frequency of SGMA. b) Effect of variation of slot length *w*2 on the resonant frequency of SGMA.

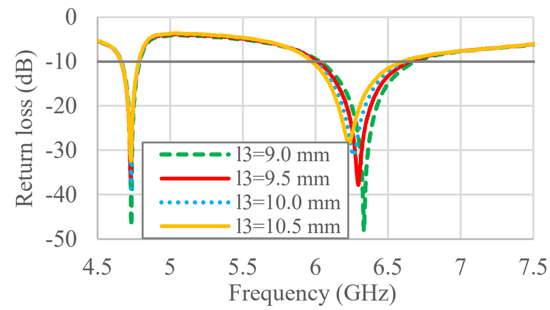
B. Gain

The measured gain plot shown in Fig. 7 reveals the fact that the gain varies between 0.5 dB and 1.4 dB in the band I and between 1.5 dB and 3.5 dB in band II. The values of gain at resonance are approximately 1.2 dB and 3.4 dB in the band I and band II respectively. One of the main parameters which affect the gain of an antenna is the area of the radiating patch [17]. Since the radiating surface of slotted antennas is lesser than the one without slots, the value of gain of slotted antennas is comparatively lesser than the antennas without slot.

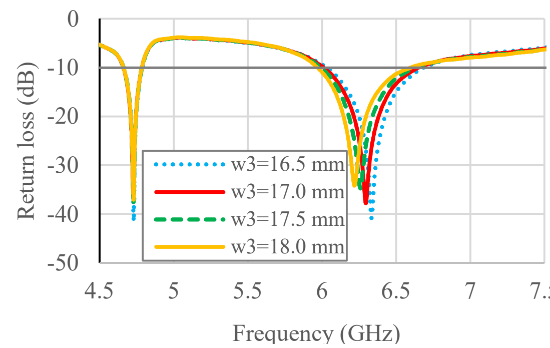
C. Radiation Patterns

The normalized co-polar and cross-polar radiation patterns in *YZ* plane and *XZ* plane are plotted for the resonant frequencies 4.73 GHz and 6.29 GHz. These simulated patterns affirm that the proposed antenna will radiate around beam angle θ = 0° and θ = 180° i.e. in the +*z* axis and −*z* axis.

The plots also show that there is adequate isolation between the co-polarized and cross-polarized patterns in the *YZ* plane for a beam width of 180° in the −*z* direction except for an angle of 30° in both sides of the major lobe (i.e. θ = 130°–160° and θ = 200°–230°).

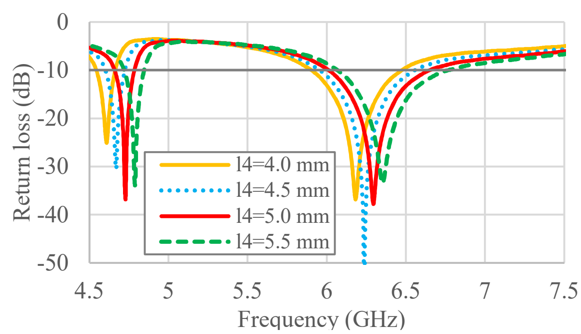


(a)

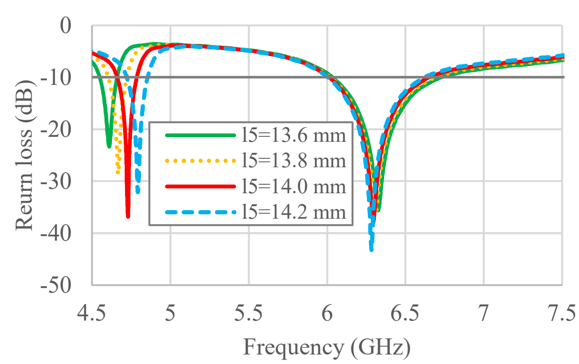


(b)

Fig. 5. a) Parametric analysis on the width of the U-shaped cut b) Parametric analysis on the length of the U-shaped cut.



(a)



(b)

Fig. 6. a) Parametric analysis on y-axis position of slot 1 b) Parametric analysis on y-axis position of slot 2.

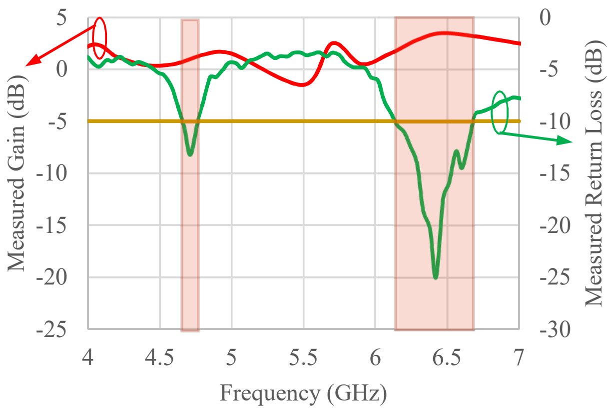


Fig. 7. Variation of measured gain with measured return loss.

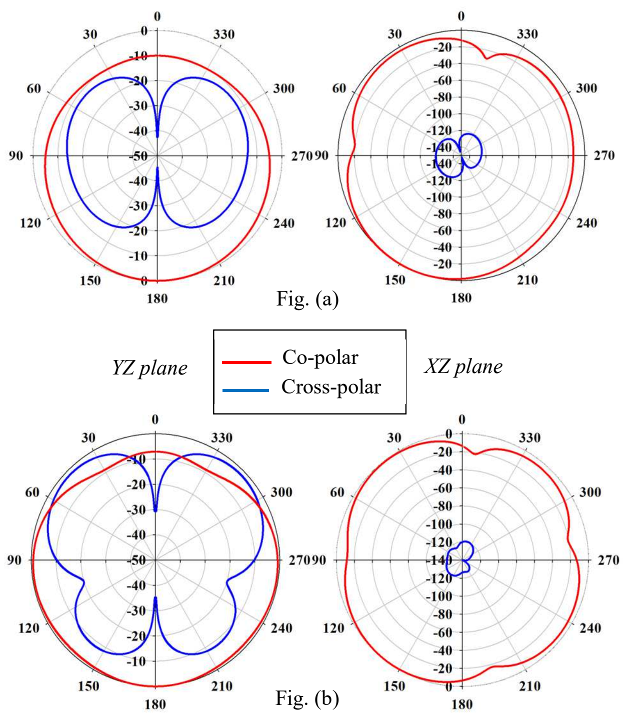


Fig. 8. Normalized radiation patterns at a) 4.73 GHz and b) 6.29 GHz

Whereas in the *XZ* plane, excellent isolation of more than 100 dB is exhibited between the co-polar and cross-polar radiation patterns for the entire 360° beam angle. Moreover, the co-polar radiations in the *XZ* plane display almost omnidirectional patterns for both the resonant frequencies

D. Comparison

Dual band microstrip antennas reported in the literature are compared with the proposed antenna in Table 3. The values of antenna parameters which were not specifically mentioned in the reported articles are taken as approximate values from their corresponding plots. Narrow operative bandwidth with good return loss and fair gain are showcased by the proposed antenna. The antenna suits the bandwidth requirements for any location tracking application. Also, the overall dimension of SGMA proves its compactness.

IV. Conclusion

The proposed antenna exhibits excellent return loss and adequate impedance bandwidth required for antennas to be used for any location tracking gadgets operating in the officially allotted UWB band. The measured return loss plots confirm the presence of two radiating bands viz. 4.66 – 4.77 GHz (the band I) and 6.13 – 6.67 GHz (the band II) with a passband of 110 MHz and 540 MHz respectively. It also displays fair gain throughout the two bands providing a measured gain of 1.2 dB and 3.4 dB at the point of resonance in the band I and band II respectively. The signals from SGMA can radiate around θ = 0° and θ = 180° providing sufficient isolation between co-polarized and cross-polarized radiation patterns. This work can be extended to roof the entire bandwidth of the declared LT bands.

TABLE 3. COMPARISON WITH REPORTED DUAL BAND MICROSTRIP ANTENNAS

Ref	***Substrate size (mm)***	***Operating bands (GHz)***	***Bandwidth (MHz)***	***Return loss (dB)***	***Peak gain (dBi)***
[3]	40 × 40 × 1.0	2.4–2.485	85	-14	3.2
		5.15–5.825	675	-40	5.5
[4]	12 × 8 × 1.5875	5.043–5.364	321	-18	1.71
		5.718–5.874	156	-26	2.12
[5]	34 × 46 × 0.508	2.40–2.483	83	-16	7.3
		5.15–5.35	200	-25	8.7
[7]	42 × 54 × 1.524	2.165–2.235	70	-20	1.1
		6.355–6.445	90	-17	6.5
[9]	15.8 × 11.9 × 1.48	2.305–2.595	290	-14	5.6
		4.745–5.255	510	-16	11.4
[10]	30 × 50 × 1.54	1.850–1.930	80	-14	1.0
		3.480–3.570	90	-11	2.4
[11]	60 × 60 × 1.6	3.1–3.4	300	-17	3.0
		5.2–6.5	1300	-18	6.0
[13]	40 × 40 × 1.6	2.37–2.56	190	-17	1.8
		5.15–6.22	1070	-25	4.3
[15]	15 × 20 × 1.5	2.846–3.24	394	-15	1.0
		4.05–6.22	2170	-19	2.0
This work	**30 × 30 × 1.6**	**4.66 – 4.77**	**110**	**-13.2**	**1.4**
		6.13 – 6.67	**540**	**-24.9**	**3.5**

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