Design of a high bandwidth Ku-band patch antenna with double-L shaped parasitic components and loaded with superstrate

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Abstract: **This paper presents a microstrip antenna resonant at Ku-Band. Operating frequency (11.81 GHz – 18.47 GHz) covers the complete Ku-band. The antenna maximum dimensions are 30 mm by 30 mm. Patch footprints are 6.4 mm x 7.1 mm. Antenna successfully manages to attain quite good gain and very high bandwidth of about 45%. The antenna is designed and simulated using HFSS 11.1.1. K_u band is primarily used for satellite communications, most notably for fixed and broadcast services, and for specific applications such as relay satellites for both space shuttle and space station communications.**

Keywords: **Ku-band, parasitic strips, superstrate, substrate, broadside, VSWR**

1. Introduction

K_u band is not limited in power to avoid interference with terrestrial microwave systems & power of its uplinks & downlinks can be increased as compared to C-band. This higher power can also be converted into smaller receiving dishes.. As power increases, dish's size can decrease. This is because the purpose of dish element of antenna is to collect incident waves over an area & focus them all onto antenna's actual receiving element, mounted in front of dish (& pointed back towards its face); if waves are more intense, fewer of them need to be collected to achieve same intensity at the receiving element.

Also, as frequencies increase, parabolic reflectors become more efficient at focusing them. Focusing is equivalent given size of the reflector is same with respect to wavelength. At 12 GHz a 1-meter dish is capable of focusing on one satellite while sufficiently rejecting signal from another satellite only 2 degrees away. This is important because satellites in FSS (Fixed Satellite Service) service (11.7-12.2 GHz in the U.S.) are only 2 degrees apart. At 4 GHz (C-band) a 3-meter dish is required to achieve this narrow of a focus beam. For K_u satellites in DBS (Direct Broadcast Satellite) service (12.2-12.7 GHz in U.S.) dishes much smaller than 1-meter can be used because those satellites are spaced 9 degrees apart. As power levels on both C & K_u band satellites have increased over years, dish beam-width has become much more critical than gain.

K_u band also offers a user more flexibility. A smaller dish size & a K_u band system's freedom from terrestrial operations simplify finding a suitable dish site. For end users K_u band is generally cheaper & enables smaller antennas (both because of higher frequency & a more focused beam). K_u band is also less vulnerable to rain fade than Ka band frequency spectrum.

The designed antenna can act as a feeder to a receiving parabolic antenna. Antenna is very small and has a very good bandwidth.

1.1. *Parasitic elements:* These elements help increase the bandwidth and sometimes the gain. They are better as compared to active array formation because parasitic array take energy from near field radiation from the active antenna. So they do not need separate supply.
1.2. *Superstrate:* Addition of a superstrate over the patch helps in increasing the overall gain of the antenna. An important qualification criterion for this is that the permittivity of the superstrate should be higher than the permittivity of substrate.

2. Antenna Geometry

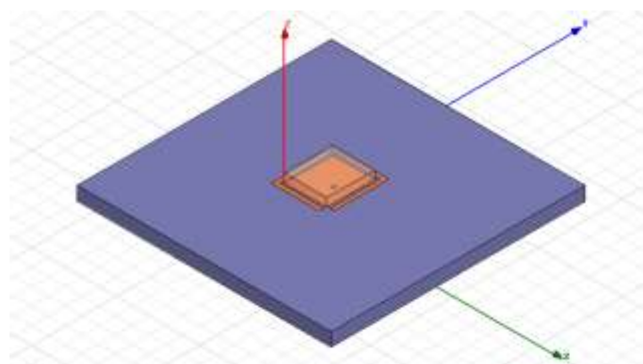

Fig. 1 Proposed antenna design

The antenna contains a Microstrip patch of size 5mm by 5.7mm. Since the bandwidth and gain of the basic patch antenna is low some more additions are done. To increase the bandwidth, L-shaped strips are added on the two diagonal corners of the patch at a distance of 0.8 mm. Thickness of the L shaped parasitic strip is 0.5 mm.

Height of the substrate is 1.6 mm. Height of the superstrate is 1 mm. The superstrate is kept such that it completely covers only the patch and not the substrate or parasitic L strips.

Substrate is made of Roger RT/duroid 5880 with relative permittivity 2.2 and dielectric loss tangent 0.0009. On the other hand superstrate is FR4 epoxy with relative permittivity 4.4 and loss tangent 0.02. We can see that even a lossy dielectric as a superstrate can contribute in increasing the gain. The gain is increased by a factor of more than 2 dB.

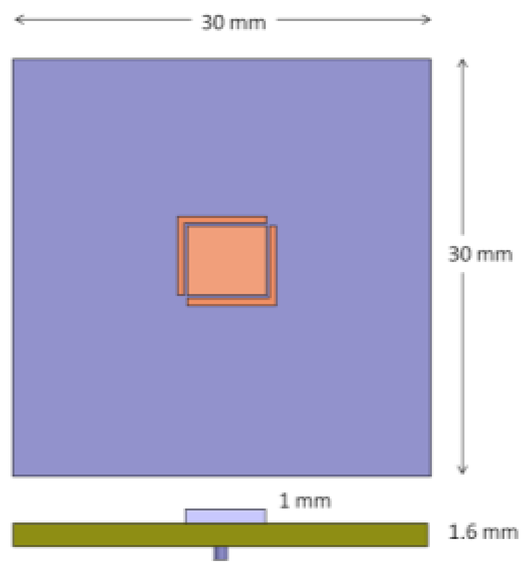

Fig. 2 Antenna Top and Side View

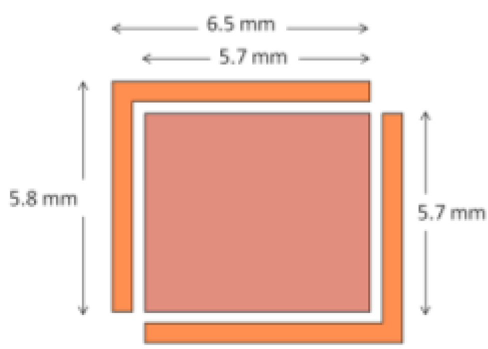

Fig. 3 Patch Dimensions

3. Design Methodology

Following formulae are used to design a basic patch antenna:

a. For an efficient radiator, a practical width that leads to good radiation efficiencies is

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{\upsilon_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

Where υ_0 is the free-space velocity of light.

b. Determine the effective dielectric constant of the microstrip antenna using

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2}$$

c. Once W is found using, determine the extension of the length ΔL using

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)}$$

d. The actual length L of the patch can now be determined by

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L$$

Values of ε_r and h are chosen according to one's convenience

3. Simulation Results

3.1. Return loss

Efficiency of an antenna at a given frequency can be estimated by measuring the return loss (i.e. S11 parameter). Return loss of an antenna tells how much supplied power is not used by the antenna. The proposed antenna has lowest value of return loss less than -30dB.

Fig. 4 S11 rectangular plot

3.2. Bandwidth

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate as promised. The bandwidth can be estimated from S11 graph. -10 dB is taken as the reference and the first and the second intersection of the return loss curve with -10 dB line is taken as f_L and f_H respectively. The center frequency f_C is 15 GHz and the bandwidth is given by $[f_H - f_L]$. Where $f_H = 18.47\ GHz$ and $f_L = 11.81\ GHz$. The bandwidth of the proposed antenna is 6.66 GHz. Percentage bandwidth is calculated as

$$\text{Percent Bandwidth} = \frac{f_H - f_L}{f_c} \times 100$$

Percentage bandwidth resulted about 44 %.

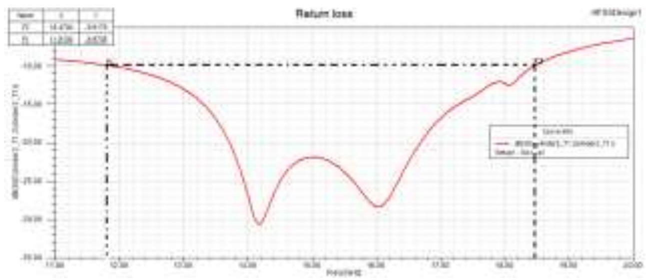

Fig. 5 Bandwidth about 6.66 GHz

Fig. 8 3D radiation pattern

3.3. Voltage standing wave ratio (VSWR)

VSWR (Voltage Standing Wave Ratio) is also an important parameter which gives an estimate of the amount of power reflected to the transmission line that is feeding the antenna. VSWR ideally should be 1 means no power is reflected from the antenna. Any value of VSWR below 2 and more than or equal to 1 is practically good. The proposed designed show excellent VSWR bandwidth. VSWR is below 2 between 11.4 GHz to 18.6 GHz.

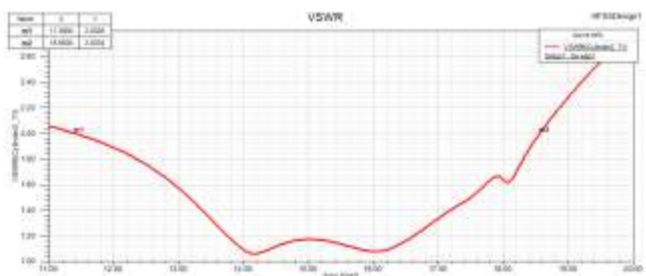

Fig. 6 VSWR

3.4. Radiation Pattern

The radiation pattern of the proposed antenna is broadside. Figure 7 show the pattern from xz and yz planes. Figure 8 show the 3D shape of radiation pattern.

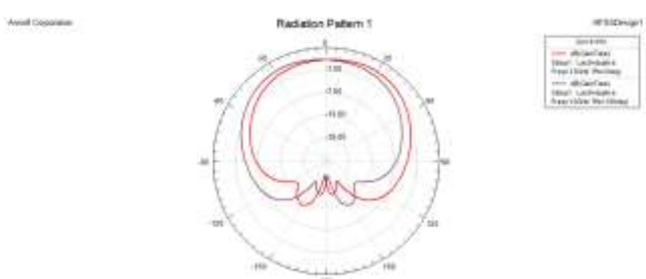

Fig. 7 2D radiation pattern

3.5. Gain

Gain of the antenna in the Ku band is shown in figure 9. Gain bandwidth as we can see is also very good. Taking the reference of 2 dB on y-axis we can see that a decent gain is extended for 4.4 GHz. Maximum gain is 4.53 dB at a frequency of 13.8 GHz.

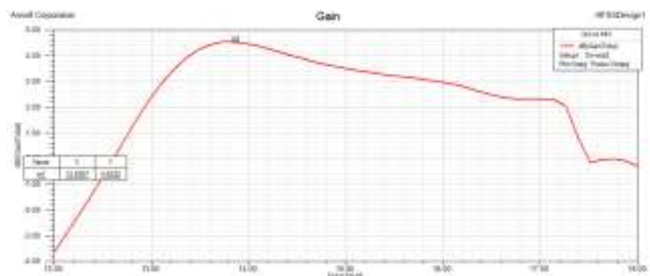

Fig. 9 Gain vs frequency (max 4.53 dB)

3.6. Electric field distribution

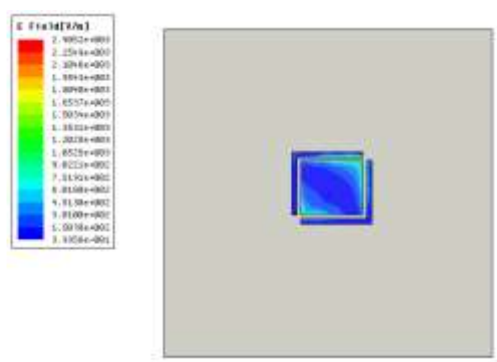

Fig. 10 E-Field magnitude plot

The table 1 shows all the simulation result in tabular format.

Table 1: Compilation of result

Parameters	***Proposed work***
Frequency of operation	11.81GHz and 18.47GHz
Bandwidth	6.66 GHz (44 %)

VSWR	< 2 (11.4 GHz to 18.6 GHz)
Return loss	less than -30 dB at 13.8 GHz
Gain	4.55 dB (max.)

5. Conclusions

The resonant frequency increases with the dielectric constant of the superstrates thickness. In addition, it has also been observed that return loss and VSWR increases, however bandwidth and gain decreases with the dielectric constant of the superstrates. On the other hand, parasitic strips increased the bandwidth but a small amount of decrease in gain is also observed. Combination of both the techniques helped in achieving good gain with very high bandwidth.

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