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Design, Construction and Performance Analysis of Helical Antenna Operating at 5.8ghz

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Abstract: *There is also a continued demand for data transmission at higher rates and over longer distances. Therefore, an antenna which is an indispensable element of any wireless and mobile communication system is now at the forefront of research activities. In many cases, antenna properties can be calculated theoretically very accurately. However, for complex antennas this might not be possible because of too many idealizations or simplifications have to be made. Another alternative method to generate high frequency signal power with low phase noise is to generate a high-quality lower frequency signal and employ a frequency multiplier to deliver the high frequency output at the desired frequency. The research was primarily focused on the design, construction and analysis performance of helical antenna operating at 5.8GHz.To achieve this, principle of positive feedback was employed on the frequency multiplier circuit. The reason for this characteristic is that a frequency multiplier is in fact a phase multiplier, so it multiplies the phase deviations as well as the frequency of the input signal. Two different software were also used both for the design and simulation of the designed antenna. Numeric Electromagnetic Code (4NEC2) which is a completely free window based tool suite to aid in the design and optimizations of antenna system. It models use a 3-D coordinate system to define antenna structure. The HFSS software provides more information on the structure of antenna, parameters and smith chart. It also allow plot of 2D and 3D polar as well as rectangular plots with a variety of variables. For transmitting antenna designs, apart from the actual E-field pattern there is a variable called Dir (or directivity) which includes DirTotal, Dirphi, DirTheta, Dir X, Y, Z etc. The Smith chart is one of the most useful graphical tools for high frequency circuit applications. The chart provides a clever way to visualize complex functions and it continues to endure popularity, decades after its original conception. From a mathematical point of view, the Smith chart is a 4-D representation of all possible complex impedances with respect to coordinates defined by the complex reflection coefficient. The axial ratio of the antenna using equation 3.37 was calculated to be 1.07 which is in line with theory that the axial ratio of a helical antenna was a unity. The pitch angle at which the designed antenna works using equation 3.23 was found to be 15.9^0. From equation 3.24, the wavelength of the antenna was found to be $5.175 10^{16} m$, it means that the higher the frequency, the lower the wavelength. In increasing the inductor, L, and capacitors used for constructing the frequency multiplier circuit was in line with the choice of values. From equation 3.41, the capacitor used was 2.7pF (C10 from the frequency multiplier circuit) and the calculated value was found to be 1.1pF. It means that 1.1pF can also be used as an equivalent to 2.2pF. Also, from equation 3.43, the calculated value for the inductor was $1.0\times 10^{-4} H$ while the inductor used was 100μH, it means that $1.0\times 10^{-4} H$ is an equivalent to 100μH. The voltage gain of the helical antenna operating at 5.8GHz, using equation 3.45 was found to be - 4.18 (It shows that it is a close – loop voltage gain) which is in line with the principle of negative feedback. Although negative feedback reduces the gain of an amplifier and may necessitate more stages of amplification, it has several highly desirable effects. Using equation 3.47, the voltage gain in dB was also calculated as 12.35dB which is a positive feedback. The maximum voltage for the resistor using equation 3.65 was found to be 19V which exceed the power rating of the resistor. Exceeding V_{max} causes the resistors power dissipation to exceed its power rating. Except for very large resistance values, the maximum working voltage rating is usually much large than the maximum voltage that produces the rated power dissipation. Ideally, the power dissipation in a resistor should never be more than 50% of its power rating, which is a safety factor of 2. A safety factor of 2 allows the resistor to operate at a cooler temperature than thus last longer without breaking down from excessive heat. In practice, however, as long as the safety factor is reasonably close to 2, the resistor will not over heat. C-band (IEEE 4-8GHz) frequencies weather conditions such as rain storm are used for a number of purposes. They perform better in poor weather conditions compared to other RF transmission bands such as Ku or Ka. C-band is also used for terrestrial microwave links and satellite T.V transmissions. Each of these frequencies is used for a different reason; with their own advantages and disadvantages. The higher you go in frequency the more bandwidth is available, but the equipment needs to be more sophisticated, this does not necessarily signify an overall cost increase. Antenna plot tell you where the radiation is concentrated. Patterns are usually referenced to the outer edge of the plot which is the maximum gain of the antenna. These make it easy to determine other important antenna characteristics directly from the plot. The directivity or beamwidth of the antenna is referred to as the* *'half-power' or 3dB beamwidth, the points between which half the power is radiated or concentrated, and specified in degrees. Antenna plot tell you where power is being radiated or received (since they are reciprocal). They also tell you how much degradation you can expect if the antenna is not aimed properly. Sometimes it is desirable to communicate with more than one station. Plots will also assist in proper aiming of the antenna for optimum performance on all the desired signals. The narrower the beamwidth, the greater the difficulty in properly aiming the antenna. If there are interfering signals, they may be picked up by the antenna. When you have a plot, you can determine the actual level of such signals. If there are interfering signals, the radiation plot can be used to minimize them by placing such signals in a null or low side lobe position.*

Keywords: *design, construction, performance, analysis, helical antenna, operation.*

1. INTRODUCTION

Communication is a vital part of personal life and is also important in business, education and any other situation where people encounter each other. Information dissemination, the major objective of communication is achieved by three electronic gadget (radio, television and mobile phones) known as radio systems of telecommunication. The successful design of this radio system depends on a crucial element called an *antenna* which is the part through which radio frequency energy is coupled from the transmitter to the outside world and in reverse to the receiver from the outside world. The recent explosion in information technology and wireless communication (such as having a bad signal when the receiver is too far from the transmitter) has created many opportunities for enhancing the performance of existing signal transmission and processing systems.

The antenna is defined as a means of radiating or receiving radio waves. It is an arrangement of electrical conductors made to efficiently radiate and receive electromagnetic waves in desired directions. It is also considered to be an interface and a guiding structure between a transmission line and space; that is, it acts as matching systems between sources of electromagnetic energy and space. (Kraus, *et al.*, 2006).

All electronic communications systems consist of a transmitter, a receiver, and a communications medium. In some systems, the transmission medium is a direct link such as wire, cable, or fiber-optic cable. In radio communications systems, there are no direct connections. The system is wireless. The RF signal generated by the transmitter is sent into free space and is eventually picked up by the receiver. The processes of launching the signal into space and receiving it are the functions of the Antenna. The antenna is a device that acts as the interface between the transmitter and free space and between free space and the receiver. It converts the transmitter RF power into electromagnetic signals that can propagate over long distances, and it is also the device that picks up the electromagnetic signals and converts them into signals for the receiver. Since the antennas are typically located remotely from the transmitters and receivers, some means must be used to get power to and from the antenna. This is the job of the transmission line, a special kind of cable.

An antenna came into being through an Italian electrical engineer and inventor Guglielmo Marconi. He designed cohere and connected it to a rudimentary form of antenna with its tower and grounded. He also develop spark oscillator connected to crude antenna. The transmitter was modulated with an ordinary telegraphy key. The Cohere at the receiver actuated a telegraphy instrument through a relay which produce fine tune as a crude amplifier.

The first antenna dates from [1887] when Heinrich hertz designed a brilliant set of wireless experiment to test James Clerk Maxwell's hypothesis. Hertz used a flat dipole for a transmitting antenna and a single turn loop for a receiving antenna. For over fifty years antenna technology has based on the radiating element configured out of wire and generally supported by wooden poles. These antennas were the mainstay of the radio pioneers including Guglielmo Marconi, Edwin Howard Armstrong and Lee Deforest. Each of these has been called the father of radio. The first generation antennas were narrow band (small range of the order of a few percent around the designed operating frequency) and were often arranged to increase creativity.

The helical antenna has a long history and has been the object of much study and development over the last half century since its invention in 1946 [Kraus, 1976]. It is an interesting antenna with unique characteristics, being capable of high gain, wide bandwidth, and circular polarization. As a result, it has been used in a wide range of applications including satellite communications, radio astronomy, TV signal transmission and wireless networking.

The helical antenna is a hybrid of two simple radiating elements, the dipole and Loop antennas. A helix becomes a linear antenna when its diameter approaches zero or pitch angle goes to 90^o. On the other hand, a helix of fixed diameter can be seen as a loop antenna when the spacing between the turns vanishes ($a = 0^o$).

Helical antennas have been widely used as simple and practical radiators over the last five decades due to their remarkable and unique properties. The rigorous analysis of a helix is extremely complicated. Therefore, radiation properties of the helix, such as gain, far-field pattern, axial ratio, and input impedance have been investigated using experimental methods, approximate analytical techniques, and numerical analyses.

After the first demonstration of wireless technology by Heinrich Hertz and the application in practical radio communication by Guglielmo Marconi, the antenna has been a major building block in the construction of every wireless communication system. (Visser, 2005) The wireless revolution is one of the most powerful means of change in the lifestyle of man. This revolution is creating a flood of new wireless devices that dramatically increase the availability of voice and data nearly anywhere in the world. While this revolution is significantly expanding the opportunity for new and better wireless communication terminal, it also requires improved antenna design.

A helical antenna is an antenna consisting of a conducting wire wound in the form of helix(John D. Kraus and Ronald J.Marheka ,2002). Many works was carried out by researchers on helical antenna at different frequencies. A.R. Djordjevic et al, (2007) work on why does reflector enhance the gain of helical antenna at 1.21-2.21GHz. A modern approach for design and optimization of helical antenna used at transmitting end of GPS at 1.58GHz (B. Venkateshwar Rao et al, 2013),

A compact ultra-wideband and microstrip antenna with multiple notches at the frequencies of 2.4GHz, 3.5GHz, 5.5GHz, and 7.6GHz was achieved separately (X.-C Yin et al, 2008). Helical antennas in satellite radio channel at 2.43GHz (Maja Skiljo et al, 2011).

Biswarup Rana et al,(2014) worked on high gain circularly-polarized dielectric resonator antenna array with helical exciter at center frequency of 5.2GHz. S.H. Zainud-Deen et al,(2012) also worked on dielectric resonator antenna mounted on cylindrical ground plane for handheld RFID reader at 5.8GHz.

(Stutzman and Thiele,1998), which give rise to radiation pattern maxima along the axis of the helix. Various modifications of the conventional helical antenna have been proposed for the purpose of improving its radiation characteristics (Nakano, Samada and Yamauchi,1986).

The phenomenon of electricity and magnetism on a macroscopic scale is governed by Maxwell's equations (Clarke and Brown, 1980). The experimental law governing the forces between current elements is generally described by Biot and Savart (Clarke and Brown, 1980).

With recent advances in RF and Microwave technology, the output capability of the RF technology (solid state devices, microwave monolithic integrated circuit(MMIC), Ferroelectric etc.) at microwave frequencies has changed the traditional scheme of most communication terminals (example the radar application where a high power pulse generated by a magnet is transmitted using a single antenna) to a scheme where multiple transmitters/receivers each combining with a fraction of the total output power, combine for transmitting/receiving. This scheme has brought about the development of array antennas system.

2. MATERIALS AND METHODOLOGY

Materials used for constructing the helical antenna are follows; Copper wire with standard wire gauge (SWG) 21.5,thickness of the copper wire 0.84mm, glass tube, Reflector, F-connectors, adhesive, digital Vernier calliper and solder

2.1. Design Methodology

The design of helical antenna was based upon the antenna parameters. In order to find any of the parameters, the following set of empirical formulae was considered (K.D Prasad and Mathew N.O Sadiku, 2007)

Directive Gain $G = \frac{15NSC^2}{\lambda^2}$ 2.1.1

Gain in dB = 10.8+10Log $[\frac{C^2 NS}{\lambda^2}]$ dB 2.1.2

Half Power Band Width (HPBW) = $[\frac{52}{C}\sqrt{\frac{\lambda^2}{NS}}]$ degree 2.1.3

Beam width between first Nulls = $[\frac{115}{C} \times \sqrt{\frac{\lambda^3}{NS}}]$ degree 2.1.4

Effective aperture $A_{eff} = \frac{C\lambda^2}{4\pi}$ square unit 2.1.5

Terminal impedance = $[140\frac{C}{\lambda}]$ ohms 2.1.6

Axial ratio AR = $[\frac{2N+1}{2N}]$ 2.1.7

Bandwidth (BW) = $\frac{F_H - F_C}{F_C} \times 100\%$ 2.1.8

$BW_{broadband} = \frac{FH}{FL}$ 2.1.9

2.2. Design Parameters of the Helical Antenna

Figure1(a and b). *Helix geometry*

Figure2. *Helical antenna*

Diameter of helix D = $\frac{C}{\pi}$, 2.2.1

Where C is the circumference of helix

D = 17.97mm.

Hence the radius of the helix R = 8.985mm.

Circumference of Helix C = πD) 2.2.2

C = 56.45

Pitch angle $\alpha = tan^{-1}\frac{S}{C}$. 2.2.3

$\alpha = 15.9^0$

Frequency = 5.8GHz

Wavelength $\lambda = \frac{c}{f}$, 2.2.4

$\lambda = 5.175 \times 10^{16}$ m.

S = 16.08mm (Spacing between turns) measured by digital Vernier caliper.

N = 7 (Number of turns).

Polarization = Circular

Axial ratio AR = $[\frac{2N+1}{2N}]$

From equation 3.12 Gain in Db = 10.8+10Log $[\frac{C^2NS}{\lambda^2}]$ dB

Where S is the Spacing between helix turns, N number of turns, C is the speed of light and λ is the antenna wavelength.

The antenna Gain = 32.08dB

Pitch angle $\alpha = 15.9°$

Height of antenna is known by formula H = N× S, 2.2.5

Where H = height of the antenna.

N = number of turns,

S = spacing between two turns.

H =112.56 mm.

2.3. Power Supply (12vdc) Circuit

The power supply consist of a transformer 220/240VAC 50Hz supply, rectifier DI-D4 IN4007, electrolytic capacitor C1 1000μF, C2 1μF and voltage regulator LM7812.

$I = I_O \sin(2\pi f t)$ 2.3.1

Where I_O is the peak value of the current

f is the frequency independent of the constant of the circuit.

I is the instantaneous current.

$V_S = \frac{N_s}{N_p} \times V_P$ 2.3.2

Equation 3.32 gives the secondary voltage of the transformer.

The output wave form from the transformer is given by;

$V_S(t) = V_m \sin 2\pi f t$ 2.3.3

The output on the load is given by;

$V_L(t) = V_m [\frac{2}{\pi} - \frac{4}{3\pi}\cos 2\pi(2f)t - \frac{4}{15\pi}\cos 2\pi(4f)t\ldots\ldots]$ 2.3.4

Since the diodes are identical, it does not have a line frequency component (f).

For a full-wave rectifier signal, frequency is 2f ≈ 100Hz (f_{out}).

Frequency output wave $f_{out} = 2f_{in}$ or $f_{out} = \frac{1}{T}$.

At 5.8GHz, f_{in} =2.9GHz which is true for the frequency output wave.

%regulator = $\frac{V_{no\ load} - V_{load}}{V_{load}} \times 100\%$ 2.3.5

Hence the output is a direct current (d.c).

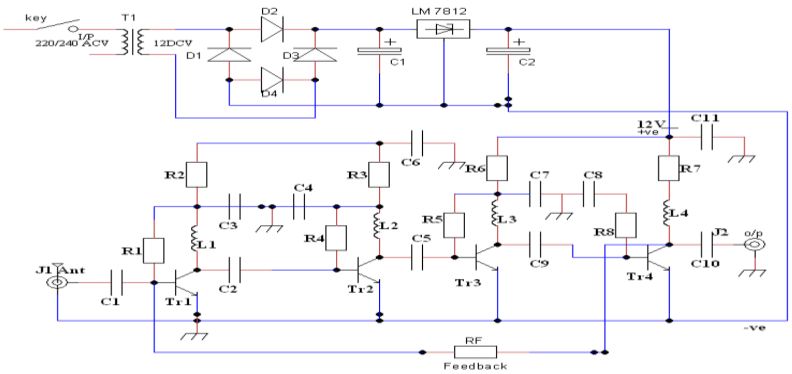

Figure3. *Complete circuit*

Figure 4.*power supply*

Figure4. *Circuit connection*

Figure5. *Top view*

The frequency multiplier circuit consist of a ceramic capacitors C1,C5= 3.3pF, C2,C9= 27pF, C3,C4,C7,C8= 680pF, C6,C11= 100pF, C10= 2.7pF, resistors R1,R5= 82kΩ, R2,R6= 820KΩ, R3,R7= 39KΩ, R4,R8= 390KΩ,RF=37.84Ω. Inductors L1, L2, L3, L4= 100µH and transistors Tr1, Tr2,Tr3, Tr4= BFR 90A.

Another alternative method to generate high frequency signal power with low phase noise is to generate a high-quality lower frequency signal and employ a frequency multiplier to deliver the high frequency output at the desired frequency. This approach was the subject of this research work. A frequency multiplier circuit contains a nonlinear device and filters that enable to select the desired component at the output and separate the source from the generated harmonics.

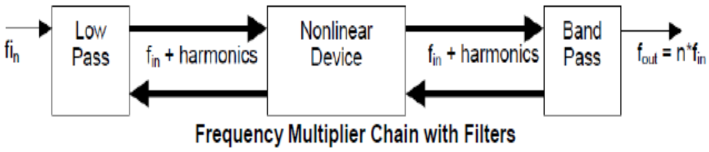

Figure6. *The frequency multiplier chain with filters.*

The nonlinear device will produce voltages of higher order from the current of the first harmonic.

One of these voltages is of the desired order and will be allowed to exit through the band-pass filter. Low-pass and band-pass filters will present high impedance to all unwanted harmonic voltages.

To deliver as much power as possible to the load the frequency multiplier should be matched at the input (for the input frequency) and at the output (for the output frequency).

3. Results

Directive Gain G = 2015.08

Gain in dB = 32.08dB

HPBW = 1.42×10^{-4} degree.

Beam width between the first null = 2.4×10^{-2} degree.

Effective aperture A_{eff} = 1.2×10^{-1} degree.

Terminal impedance = 15.29 ohms

Axial ratio AR = 1.07

f_r = 612.6Hz,

C = 1.1pF

L = 1.0×10^{-4}H

The voltage gain at 5.8GHz,

X_{C_F} = 0.27Ω.

Z_F = 0.34Ω.

A_{CL} = -4.18.

Voltage gain in dB =12.35dB

R = 2.4Ω, P =60

3.1. Simulated dimensional results.

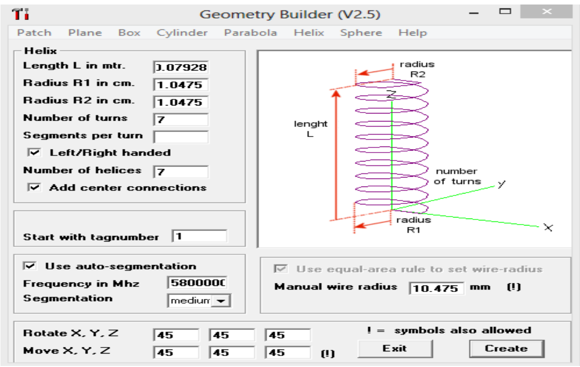

Figure7. *The 4NEC view of the antenna*

This environment allows the user to input the dimension of the design antenna such as length, radius, number of turns, tag number, working frequency so as to create the shape of the antenna. Inputting the dimensional parameters the result was obtained as shown in the figure above

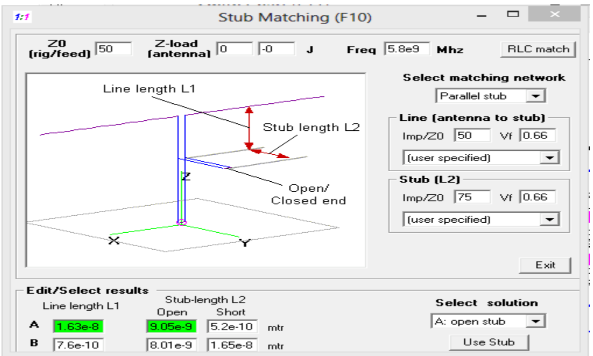

Figure8. *Stub matching*

The stub matching allows the user to specify the matching network to be used. It also displays result such as, open, closed, line length L1, stub (L2), and antenna stub.

3.2. Directivity

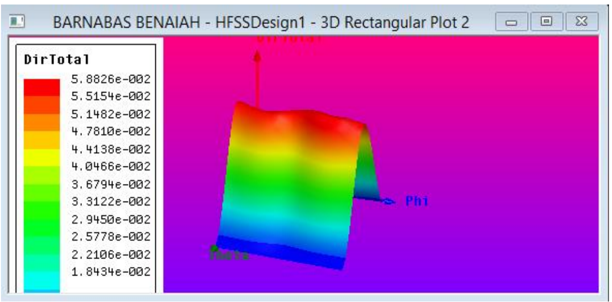

Figure9: *3D rectangular plot of Directivity Total.*

The above figure shows the simulated results of directivity in terms of field pattern in 2D polar or rectangular form which contain the F[(theta), (phi).

3.3. Gain

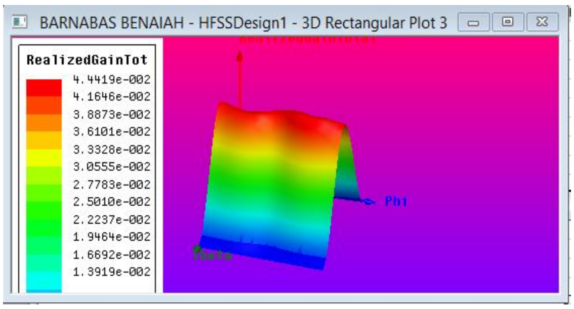

Figure10. *3D rectangular plot of realized gain total.*

The above figure shows the simulated realized gain total of the antenna. It also indicates the directivity and efficiency of a given antenna.

3.4. Polarization

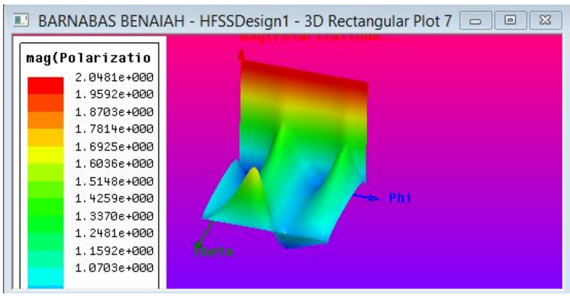

Figure11. *3D rectangular plot of mag(polarization)*

The above figure shows the directional behaviour of the electric vector of the electromagnetic wave due to the fact that the intensity of the wave is measured in terms of electric field intensity emanating from the antenna.

3.5. Axial Ratio

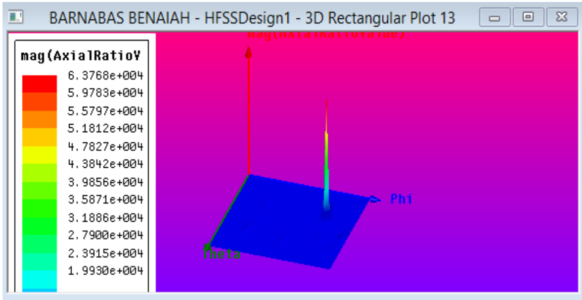

Figure12. *3D rectangular plot of mag(Axial Ratio.*

The axial ratio of the antenna concern about the size and number of turns, as the number of turn increases the axial ratio approaches unity and the polarization is nearly a circular.

3.6. Helical

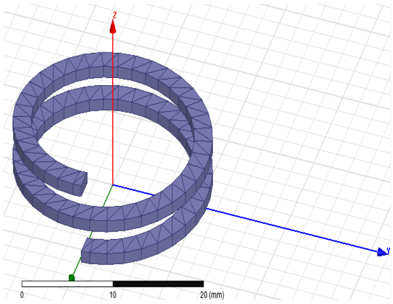

Figure13. *The shape of the helix antenna*

The above figure shows the shape of the simulated helical antenna.

4. Discussion

This research was primarily focused on the design, construction and analysis performance of helical antenna operating at 5.8GHz.

To achieve this, principle of positive feedback was employed on the frequency multiplier circuit. The reason for this characteristic is that a frequency multiplier is in fact a phase multiplier, so it multiplies the phase deviations as well as the frequency of the input signal.

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5. CONCLUSION

In conclusion, it is possible to generate higher frequencies gain using the principle of positive feedback. Smaller antennas can serve the purpose of larger antennas with the aids of a frequency multiplier. The designed and constructed helical antenna can operate within the frequencies of C-Band (4-8) GHz which also fall within the downlink (5.924-6.425) GHz. As the number of turns increases, the gain of the antenna also increases.

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