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Periodicities of Solar Wind Observed During 23 Solar Maximum

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Abstract*: As the result of solar rotations, Solar wind carries solar fluctuations to the magnetosphere. Morlet wavelet technique is used in present work to analyze the periodicities of solar wind parameters during maximum phase of 23 solar cycles. The solar wind parameters such as interplanetary magnetic field, solar wind speed, temperature and density are used to carry out the wavelet analysis. ACE observations are compared with WIND observations to verify the periodicities during solar maximum. We found out that each parameter of the solar wind exhibit certain periodicities and time evolution of these periodicities in these parameters connected with the Sun's rotation. Due to higher solar activity, the prominent short term periodicities are observed during 23 solar maximum.
Keywords: Solar Wind density, Solar Wind magnetic field, Solar Wind temperature, Solar Wind velocity, Wavelet Spectrum

I. INTRODUCTION

The basis of solar activity is the variable character of solar atmosphere an it is not homogeneous and contains diffuse structures. Some of the variations that are especially depending on are solar or planetary motions strictly periodic, but others like solar flares are only approximately aperiodic in solar cycle. Solar wind, being the continuation of solar corona, exhibits also periodic behaviour possibly be driven by the Sun periodic variations. Over the past, many studies have been made on the periodic or approximately periodic variations of the solar parameters like interplanetary parameters like IMF [3,4], solar wind velocity and plasma density [9], and plasma temperature. Different solar parameters exhibit different types of periodicities and these periodicities occur in different phases of the solar cycle. Some of the periodicities are common to all parameters and some others are found to evolve with the solar cycle.

Recent helioseismic probing of the solar interior has shown that the rotation rate of the Sun near the base of its convective zone changes [5]. Sun is a variable star that fluctuates and oscillates on various timescales ranging from seconds to several years. In particular solar activity rises and falls with the 11-year solar cycle, during solar maximum the Sun's magnetic field is predominantly toroidal, changing gradually during the declining phase to a poloidal structure [6,12]. In addition, a gradual transition from solar maximum dominated by coronal mass ejection activity to solar minimum activities dominated by regions of open flux coronal holes takes place during this phase of the solar cycle. In a solar cycle, the dipole solar magnetic field also varies as minimum during solar maximum and maximum strength during solar minimum. This work examines the periodicities of solar wind magnetic field, velocity, density and temperature within the 1999-2002 intervals which includes 23 solar maximum. The time series examined exhibit a non-stationary, quasi-periodic behaviour where periodic components appear intermittently and with varying significance levels. Solar cycles are characterized by changing recurrent geomagnetic activity which varies with the strength of the solar magnetic field and the emergence of sunspots. Fortunately, nowadays measurements of solar activity and solar wind parameters are effectively measured by a large number of operating worldwide network of ground-based observatories and space probes.

The wavelet transform is a powerful tool for analysing localized variations of power within a time series and is finding ever-widening astronomical and geophysical applications [13,1]. The wavelet transform decomposes a time series into time-frequency space, thus enabling the determination of the frequency spectrum of the variations as a function of space and time. Contrary to classical Fourier analysis that decomposes a signal into different sines and cosines which are not bounded in time, the wavelet transform uses wavelets characterized by scale (frequency) and position in time. It is therefore ideally suited for our present study.

II. DATA AND METHOD OF ANALYSIS

The daily averaged values of solar wind velocity, density, interplanetary magnetic field components, and sunspot number are subjected to periodic analysis for 24 solar maximum. The solar and interplanetary data are obtained from the official website of ACE and OMNI dataset at CAD Web for WIND in electronic form. The data from Solar Wind Observations of the Magnetic Field Experiment (MAG) [11], the Solar Wind Electron Proton Alpha Monitor (SWEPAM) [7] for ACE and Solar Wind Experiment (SWE) instrument and Magnetic Field Investigation (MFI) instrument for WIND are utilized for carrying out this work. In this

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work, the Morlet wavelet [8,13] analysis was used because it is most adequate to detect variations in the periodicities of geophysical signals in a continuous way along time scales. In order to identify the time variation of non-stationary power contained at various periods, the solar and interplanetary parameters and geomagnetic activity index are subjected to wavelet analysis. It is possible to construct a picture showing the amplitude of any characteristics versus scale and how this amplitude varies with time [13] by varying the wavelet scale and translating in time.

III. WAVELET SPECRUM OF SOLAR WIND VELOCITY

The wavelet spectrum of solar wind velocity in the period, 23 solar maximum is depicted in following figures. Fig:1and 2 displays the wavelet spectrum of solar wind density in each period range and its evolution with time during 23 solar maximum for ACE and WIND respectively. The wavelet power shows higher power in a few selected periods.

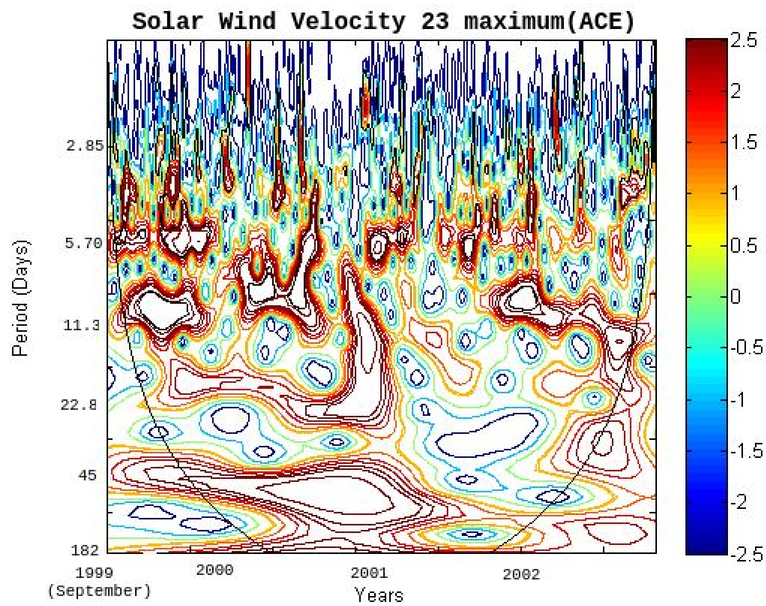

Fig. 1 shows the Wavelet spectrum of solar wind velocity for ACE spacecraft

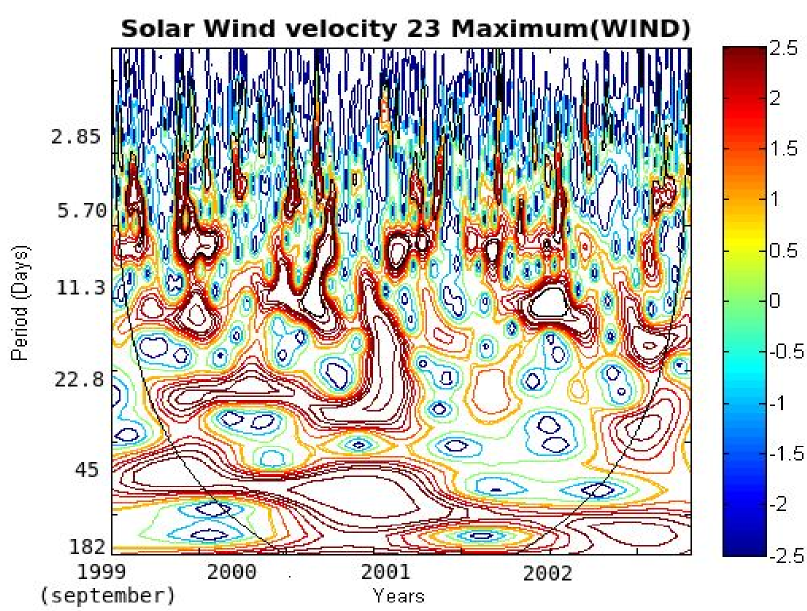

Fig. 2 shows the Wavelet spectrum of solar wind velocity for WIND spacecraft

The periods such as 9, 13.5 and 45-60 days of periods are much more intensed during the beginning phase of 23 solar maximum. Beginning of 23 maximum, periodicities of 45-2 were found by ACE and periodicities of 70-3 were found by WIND. 9 and 13.5 days of periodicities are prominent in remaining days of 2000 and 2001. But 13.5 days and 9 days of periodicities are prominent in 2002. 27 days of periodicities are also present, but it is less intense. It is noticed that the spectral power is maximum around the 13.5 day and 27 day period for both ACE and WIND observations. The amplitude of the 13.5 days period in velocity is strong and confined to a narrow band of periods. In these periods, the peak value of spectral power is concentrated around the 27-4 day periods throughout the 23 solar maximum and 11-15 days of periods are concentrates mainly in solar maximum peak.

IV. WAVELET SPECTRUM OF SOLAR WIND DENSITY

The wavelet spectrum of solar wind density in the period, 23 solar maximum is depicted in following figures. Fig:3and 4 displays the wavelet spectrum of solar wind density in each period range and its evolution with time during 23 solar maximum for ACE and WIND respectively. The wavelet power shows higher power in a few selected periods.

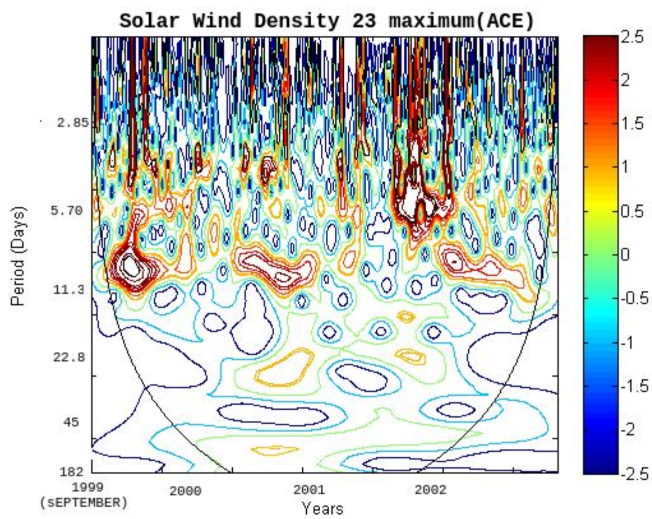

Fig. 3 shows the Wavelet spectrum of solar wind density for ACE spacecraft

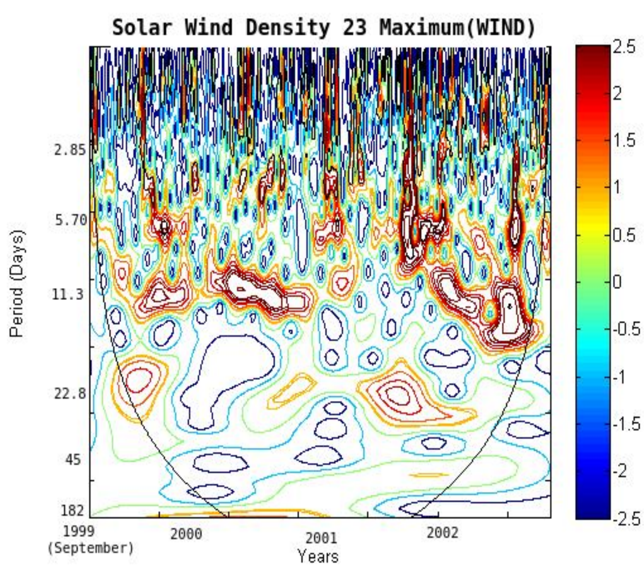

Fig. 4 shows the Waveletspectrum of solar wind density for WIND spacecraft

The evolution of wavelet power corresponding to the period of 23 solar maximum is depicted in above figures. There are many prominent periods in the range 0-13.1 days for ACE observations and 0-27 days for WIND observations. The wavelet power is comparatively much higher in the period 13.5 days during maximum phase. Both the spacecrafts, ACE and Wind observed shorter periods for solar wind density during the 23 maximum activity phase. 13.5, 5 and 2 days of periodicity is observed in solar maximum peaks. It is noticed that the spectral power is maximum around the 13.5 day and 5 day of period. The near 13.5 day periods shows strong prevalence during maximum activity, it is attributed to the active sunspot regions and related features.

IV. WAVELET SPECTRUM OF SOLAR WIND TEMPERATURE

The wavelet spectrum of solar wind temperature in the period, 23 solar maximum is depicted in following figures. Figures 1.5 and 1.6 displays the wavelet spectrum of solar wind temperature in each period range and its evolution with time during 23 solar maximum for ACE and WIND respectively. The wavelet power shows higher power in a few selected periods.

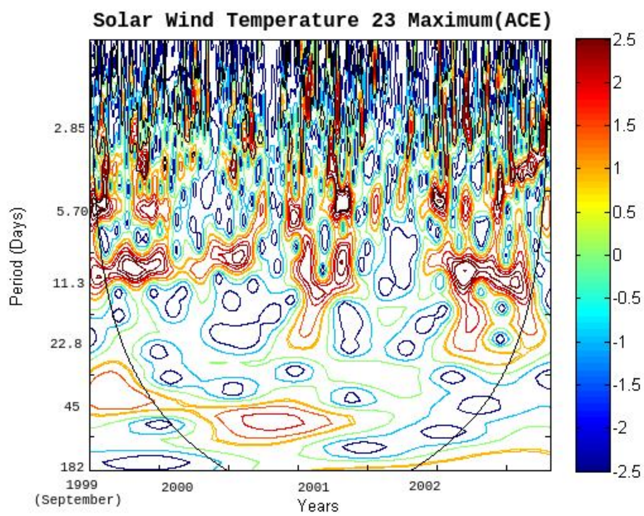

Fig. 5 shows the Wavelet spectrum of solar wind temperature for ACE spacecraft

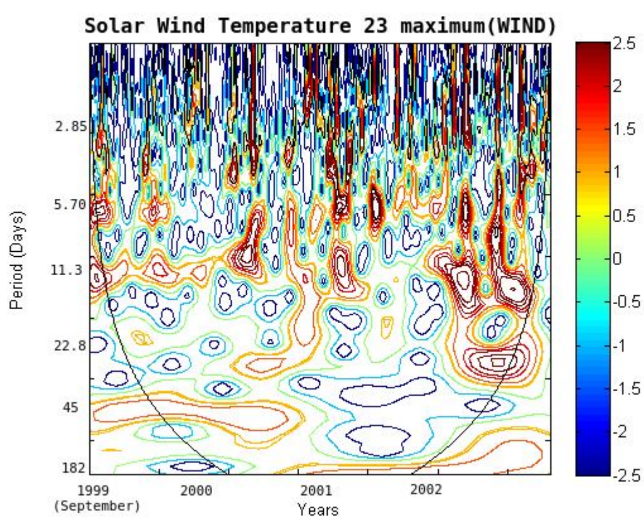

Fig. 6 shows the Wavelet spectrum of solar wind temperature for WIND spacecraft

The wavelet spectrum of solar wind temperature show 5 days and 13.5 days of prominent periodicities during 23 solar maximum. The stronger periods are mainly concentrating at shorter periods, mainly less than solar rotation periods during this time. Onset of solar maximum contains shorter periods less than 45 days. 5-45 days of periods are found in 2002 by both spacecraft. 27 days of periodicity of solar wind temperature was only observed by WIND. It is observed that strength of periodicity is maximum in during second half of solar maximum for ACE and WIND. ACE observed the periods such as above 45 days of periodicity in beginning and middle phases. But WIND observed the periods above 45 days throughout the 23 solar cycle maximum.

VI. WAVELET SPECTRUM OF SOLAR WIND MAGNETIC FIELD

The wavelet spectrum of solar wind temperature in the period, 23 solar maximum is depicted in following figures. Figures 1.7 and 1.8 displays the wavelet spectrum of solar wind temperature in each period range and its evolution with time during 23 solar maximum for ACE and WIND respectively. The wavelet power shows higher power in a few selected periods.

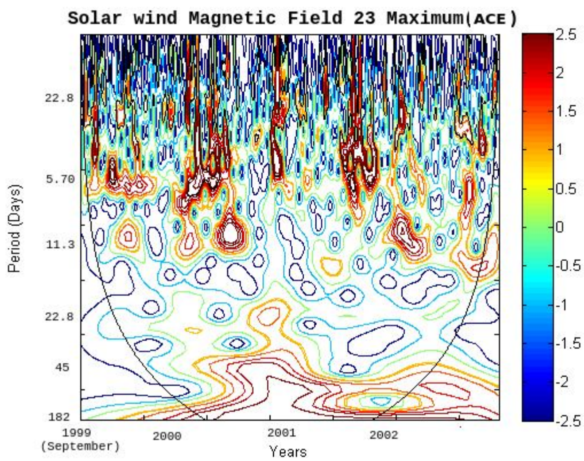

Fig. 7 shows the Wavelet spectrum of solar wind magnetic field for ACE spacecraft

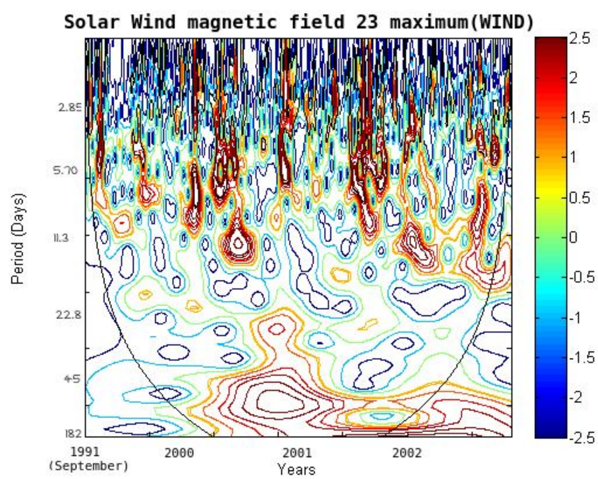

Fig. 8 shows the Wavelet spectrum of solar wind magnetic field for WIND spacecraft

The wavelet spectrum of solar wind magnetic field show 13.5 days and 5 days of prominent periodicities during 23 solar maximum. Both the spacecrafts observed more in tensed periodicity, 13.5 days of periodicity in the middle of 2000 and in the beginning of 2002. From 1999 December onwards ACE detected larger periodicity. But WIND detected larger periodicities, periodicities above 45 day, middle of 2000 onwards to the extreme of 23 maximum. The wavelet spectrum of magnetic field for ACE and WIND spacecrafts are follows the same pattern of periodicity during this solar maximum.

VII. RESULT AND DISCUSSION

The observations of ACE and WIND recorded 8 days, 13.1 days, 27 days and more than 50 days periodicities for solar wind parameters. In active phase, when the Sun is nearing the maximum phase with complicated sunspots, the 13.5 period is found. [10]. The 13.5 day period in the solar wind velocity during the maximum phase of the solar cycle is due to the presence of two stream structure associated with the two sector structure of the IMF. The coronal holes are sources of low solar wind density. So the features associated with the periodicities of solar wind velocity are applicable to the solar wind density also. During solar maximum, the solar magnetic field has dipolar as well as non-dipolar (quadruple components) components [14]. The relative strength of dipolar and non-dipolar components decides the large scale feature of the solar magnetic field and hence the IMF. The 13.5 day period of the IMF magnitude is evidently due to the dipolar nature of the solar magnetic field. The occurrence and relative power of the 13.5 day periodicity of the magnitude of IMF has somewhat different distribution over the solar cycle than solar wind velocity or density attaining more power around the sunspot maximum times [9]. The IMF will have more sectors during these periods. This may be the reason for the enhancement of 8-day periodicity in IMF magnitude and its components during the maximum phase of the solar cycle.

VII. CONCLUSIONS

The wavelet spectrum analysis of solar wind parameters during 23 solar maximum reveals the several interesting features regarding the behaviour of the Sun have been revealed by this as observed by ACE and WIND. The solar surface and interplanetary medium parameters exhibit different types of periodicities and the amplitude of these periods vary with the phase of the solar cycle. The Morlet wavelet spectral methods are used to identify the significant periods in the spectrum of solar wind velocity and density, temperature and magnetic field data observed during 24 solar maximum. The main periodicities in a time series are identified by the wavelet transform and it is also used to study the time evolution of each period. The wavelet power spectrum of solar wind velocity, density and temperature shows same pattern for both spacecrafts observations whereas wavelet

spectrum of solar magnetic field of are not like for ACE and WIND observations. Some of these periodicities like 13.1 day, 27 day are common to all parameters during this period. The solar wind number density, IMF does not show any systematic amplitude evolution in the 0-50 day period range.

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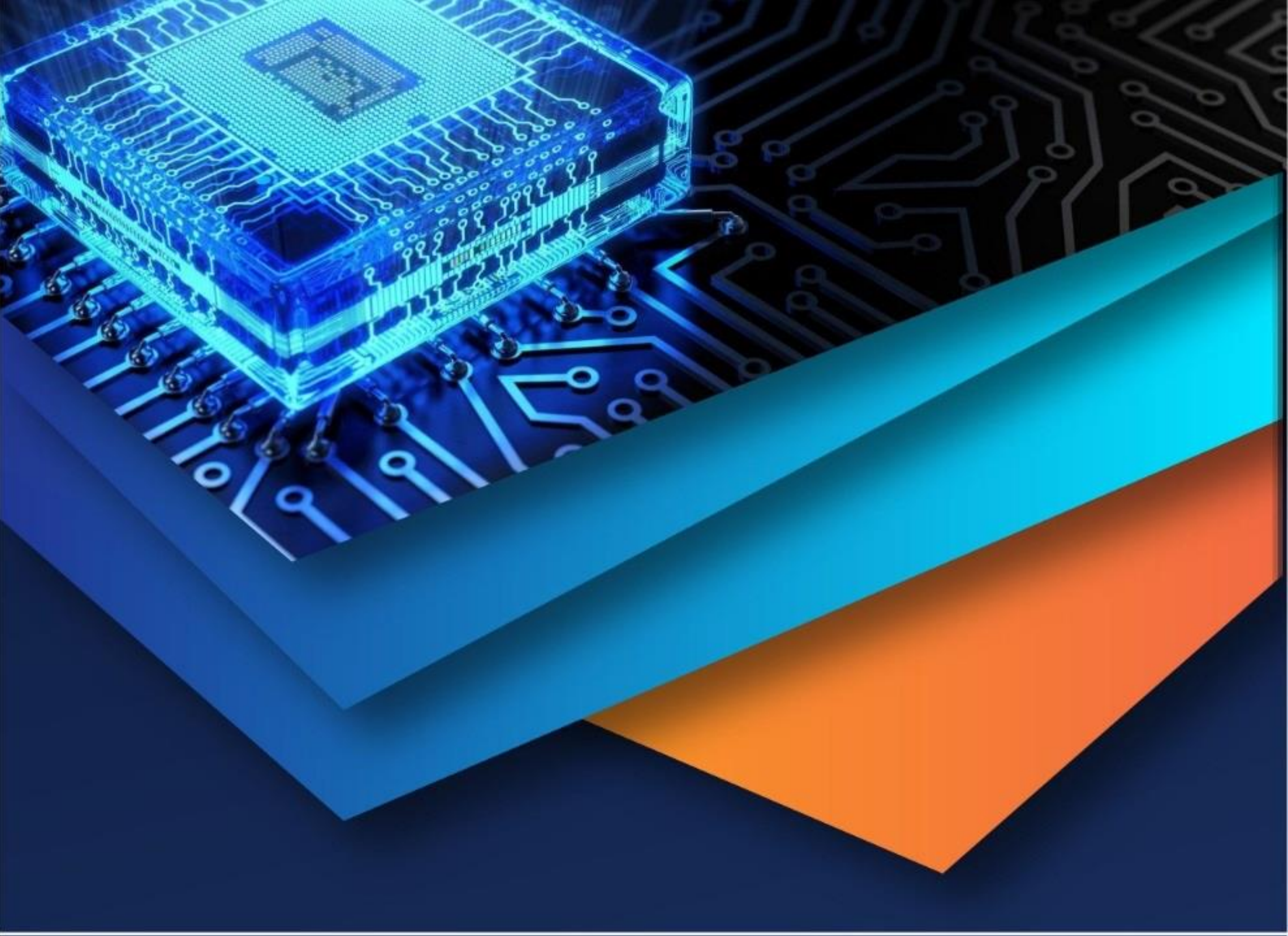

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