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Estimation of Coronal Magnetic Field Using Multiple Type II Radio Bursts

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Abstract The magnetic fields in the corona is determined using multiple type II radio bursts observed on 20 January 2004 with the Culgoora solar radio spectrograph. Using the relation between the relative bandwidth of the band-split and the density in the upstream and the downstream of the shock the Alfven Mach number is estimated. From the observed drift rates of the multiple type II bursts the Alfven speed and the magnetic field is estimated. The relative bandwidths for the first and second type II bursts respectively are 0.28 and 0.20. The Alfven Mach numbers for the first and second bursts respectively are 1.64 and 1.44. The mean frequency of the first type II burst is 73 MHz and the same for the second burst is 49 MHz. The derived magnetic field varies from 1.30 to 2.24 Gauss for the first burst and 1.32 to 2.46 Gauss for the second burst for Newkirk's density with density enhancement factors 1 to 5. The associated activities show a single flare and a Coronal Mass Ejection (CME). The results are discussed in the frame work of the single flare/CME.

Keywords Corona, Type II bursts, Shocks, Alfven velocity, Magnetic field

1. Introduction

Magnetic fields play an important role in the solar atmosphere. In the absence of magnetic field, the Sun would show only minor deviations from spherical symmetry due to the differential rotation and meridian circulation. Without the magnetic field, phenomena and process on the sun like sunspots, coronal loops, faculae, solar flares, solar wind, and prominences would be unknown to us. Magnetic field is considered to be the main factor for coronal heating, particle acceleration and the formation of structures like prominences and Coronal Mass Ejections. They also play an important role in the accumulation and release of many forms of energy in the solar surface. Measurements of the strength of the solar magnetic field had been done in the past by several methods. At the photosphere levels, Zeeman splitting of the lines in the visible part II radio bursts had been used for the determination of the coronal magnetic field (Fomichev & Chertok, 1966; Smerd et al. 1974; Karlicky & Tlamicha, 1979; Gary et al. 1984; Vrsnak et al. 2001; Cho et al. 2007). Type II radio bursts were first discovered by Wild & McReady (1950) from the dynamic spectra of solar radio bursts. In the frequency - time plane, a type II radio burst shows a drift from high to low frequency with a drift rate of 0.5 MHz/s. The slow drift rate of a type II burst is interpreted as the radio signature of a collision less Magneto hydrodynamic (MHD) shock wave generated in the tenuous solar corona (Uchida, 1960). The radio emission process of a type II burst is due to the plasma oscillations from the electron accelerated at the moving shocks (Wild et al. 1963; Nelson & Melrose, 1985). These plasma oscillations occur at the local plasma frequency and the scattering of the plasma waves on the background ions results in electromagnetic waves at the fundamental and the coalescence of two plasma waves results in the second harmonic. In some cases the fundamental harmonic bands of type II bursts are split into two, called as band-splitting. Band-splitting occurs form both the upstream (Smith, 1971) and downstream (Tidman, 1965, Tidman et al. 1966) of the coronal shock front. Smerd et al (1974) related the spectral width of the band split to the shock compression ratio which then yields the Alfven Mach Number MA under the Rankine - Hugoniot jump relation. By relating the speed of the type II radio burst to Alfven Mach number, the Alfven speed of the shock wave generating type II radio burst can be calculated. Using the relation between the Alfven speed and the mean frequency of observations, the magnetic field strength can be derived at a particular height in the solar corona. Since the MHD shock waves of the type II radio bursts sweep through the entire corona on a global scale, the measurements using type II bursts are better, since they are not confined to the flaring active regions. Again metric type II bursts occur in the solar corona at heights from 1.1 to 2 solar radii. The magnetic field in the region of 1.1 - 3 solar radii is especially important as the interface between the photospheric magnetic field and the

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solar wind. Several observations are required to estimate the strength of the magnetic field at different heights since the mean frequencies of type II bursts are different for different type II bursts. Two type II bursts sometimes occur in sequence with a time delay of 10-15 minutes and were first reported by Robinson & Sheridan (1982) and then by Gergely et al. (1984). In a dynamic spectrum, these radio bursts appear as two type II bursts occurring one after another, with both the bursts showing fundamental /harmonic bands and with a gap in emission lasting for about 10 minutes. Both these two bursts show drift from high to low frequencies. Physical properties of the two components of multiple type II bursts and the relation between the two components were studied by Shanmugharaju et al. (2005) and Subramanian & Ebenezer (2006). From a detailed statistical study of multiple Type II bursts these authors have showed that the second type II radio burst always occurs a lower frequency compared to the first type II radio burst indicating that the second type II radio burst always occurs higher in the solar corona compared to the first type II radio burst. Therefore multiple type II bursts have the advantage of estimation of the strength of the magnetic field two different heights simultaneously if both the bursts show band-split. The occurrence of multiple type II burst with band-split in both the components of multiple type II bursts is very rare. Multiple type II bursts event of January 20, 2004 which showed band split in both the bursts were analyzed and the results are presented in this paper.

2. Method, Data and Analysis

From the in-situ measurements of interplanetary shocks it had been proved by Gurnett et al., (1979) and Kennel et al., (1982) that high and low frequency plasma waves are enhanced in the shock region. Since both low and high frequency plasma waves are required for the generation of type II burst radiation, it was suggested by Mann et al (1995) and Vrsnak et al., and references therein (2001), that solar type II bursts are generated in the vicinity of shock front region of a coronal shock wave. According to Vrsnak et al. (2001), the density jump at the shock front is related to the instantaneous relative bandwidth of the band-split (Δf/f) of the type II radio burst. The method involves the assumption that in the front of the shock region (upstream), the electron density N_1 is lower and corresponds to a plasma frequency of f_l. The plane behind the shock (downstream) corresponds to the back region of the shock, where the electron density N_2 is higher and hence higher plasma frequency of f_u. The Rankine - Hugoniot relation (Priest, 1943; Tidman and Krall, 1971) gives the relation between the up and down stream quantities of the shock wave like particle density, velocity and the magnetic field. Since the plasma frequency f_p and hence the radio frequency is related to the electron density N_e by the relation

$$f_p = 9 \times 10^{-3} N^{\frac{1}{2}}$$

N is the electron density in cm-3

The relative bandwidth $\frac{\Delta f}{f}$ of a type II radio burst can be written as (Mann et al. 1995)

$$\left[\frac{\Delta f}{f} = \frac{(f_u - f_l)}{f_l} = \sqrt{\frac{N_2}{N_1}} - 1 \right] \quad (1)$$

According to Gary et al., (1984), the density jump N_2/N_1 is related to the Alfven Mach number by the relation

$$\frac{N_2}{N_1} = \frac{4(M_A)^2}{\left(3 + (M_A)^2\right)} \quad (2)$$

where M_A is the Alfven Mach number and is equal to V_r/V_A, where V_r is the radial velocity of the type II radio burst and V_A is the Alfven speed. By using a coronal density model, the radial velocity of the type II shock can be derived from the measurement of the drift rate of the type II radio burst from the dynamic spectrum. From the Alfven speed and the frequency of observation, the strength of the magnetic field can be estimated.

2.1. Data and Associated Events

In this section, we present the data and the associated events. The dynamic spectra of the multiple type II radio bursts observed on January 20, 2004, with the Culgoora solar observatory solar radio spectrograph (Prestage et al., 1994) is shown in the figure 1.Two type II bursts in sequence can be seen clearly in the dynamic spectrum both showing fundamental / harmonic structures. The band splitting can be seen in the fundamental for both the bursts. This event had been observed by the Bruny Island radio spectrograph which also show very clearly the band split and is shown in figure 2. This multiple type II bursts are not seen in the interplanetary medium as seen in the WIND / WAVES radio spectrograph. Only a strong type III burst is seen at the time of occurrence of multiple type II bursts in the WIND/WAVES spectrograph and is shown in figure 3.

For the present data analysis we use the fundamental of the first (type II_1) and the second (type II_2) type II bursts of the Culgoora radio spectrograph data. The upper frequency (fu_1) of the band-split of the fundamental of type II_1 burst in the Culgoora radio spectrograph data is around 130 MHz at the onset time (07:40 UT) and the upper frequency (fu_2) of the and-split for the type II_2 is at a lower frequency of around 67 MHz at the onset time 07:50 UT. At these times, the lower frequencies fl_1 and fl_2 of the band-split for the type II_1 and type II_2 respectively are 95 MHz and 54 MHz The mean frequency of fu_1 and fl_1 is around 112 ((130 +95)/2.0) MHz for the type II_1. The mean frequency of f_{up2} and f_{lo2} of the band-split is around 60 ((67+54)/2.0) MHz for the type II_2 burst. We have shown (Subramanian & Ebenezer, 2006) that the start frequency of second type II burst is always less than the first type II burst.

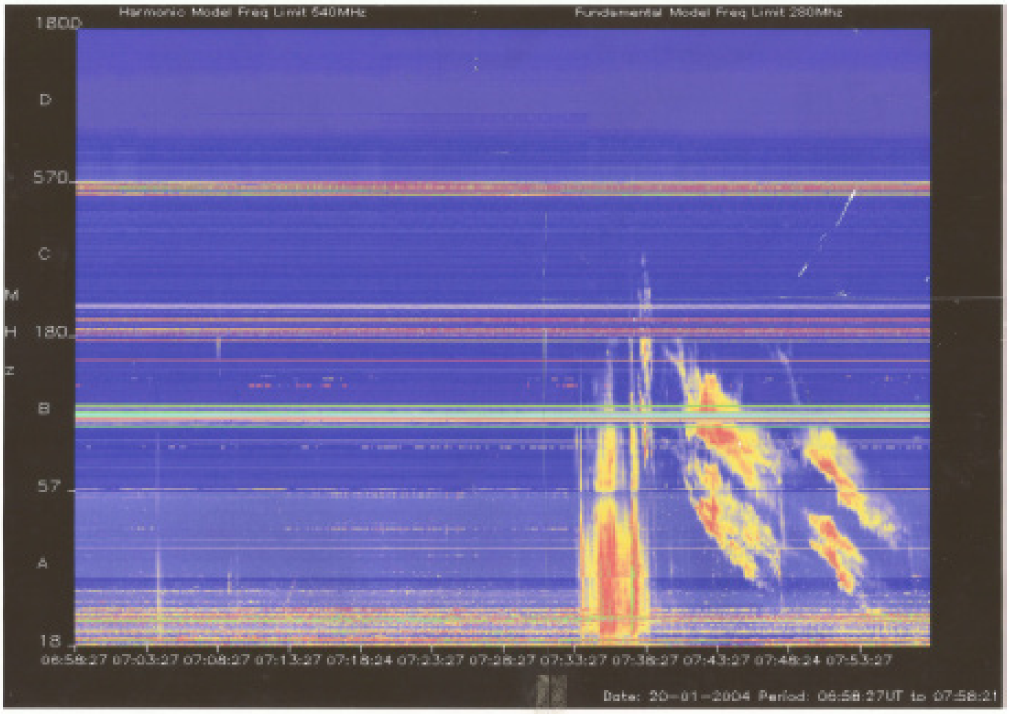

Figure 1. Radio dynamic spectrum from the Culgoora radio spectrograph showing multiple type II radio bursts. Two type II bursts can be seen in sequence with the first one starting at 07:40 UT and the second one at 07:50 UT. Both the bursts show fundamental/harmonic structures. Band split ting can be seen at the fundamental for both the bursts

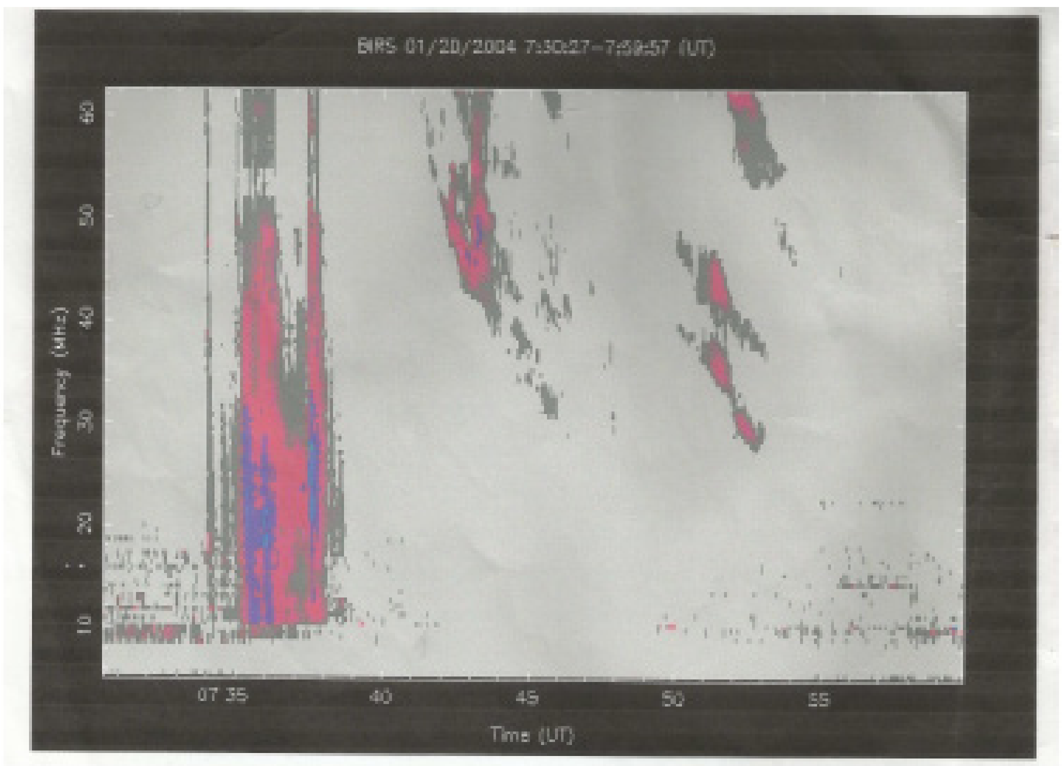

Figure 2. Radio dynamic spectrum from the Bruny island radio spectrograph showing multiple type II radio bursts. Two type II bursts can be seen in sequence with the first one starting at 07:40 UT and the second one at 07:50 UT. Both the bursts show fundamental/harmonic structures Band splitting can be seen at the fundamental for both the bursts

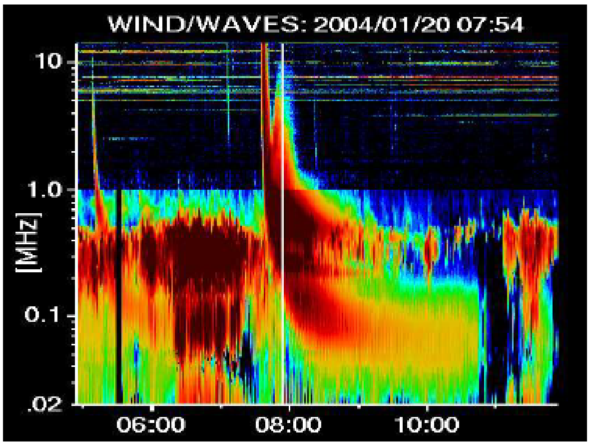

Figure 3. Radio dynamic spectrum from the WIND/WAVES radio spectrograph showing a strong type III burst at the time of the Multiple type II radio bursts

We have found the following solar activities associated with the multiple type II radio burst of January 20, 2004. There was a GOES X-ray flare, which started at 07:29:00 UT, attained maximum intensity at 07:43 UT and ended at 07:47 UT and is shown in the figure 4. The GOES X-ray flare is of M6.1 class and occurred in the active region AR 10540 located at S15W13. The type II_1 burst started 3 minutes before the peak of the GOES X-ray flare. The type II_2 burst started 7 minutes after the peak of the GOES X-ray flare. Also a CME was reported, at 08:30:15 UT at 3.99 solar radii by the LASCO on board SOHO (see http://cdaw.gsfc.nasa.gov/CME-list) as a poor event.

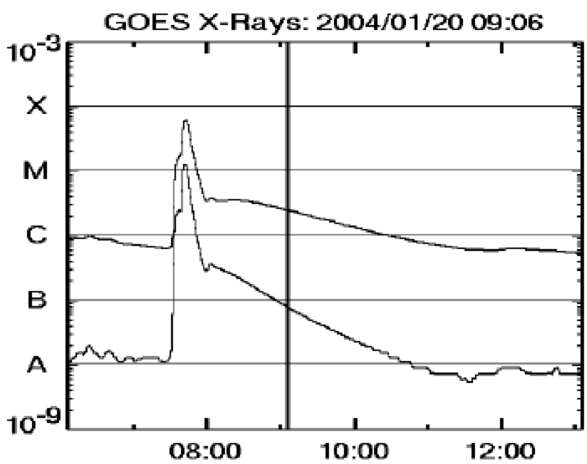

Figure 4. GOES X-ray plot of the flare activity observed on January 20, 2004 from 06:00 UT to 13:00 UT. The bottom curve is for energies in the 0.5 - 4 A° band and the upper curve is for energies in the band of 1 - 8 A°. X-ray peak observed at 07:44 UT are close to the start timings of the first type II burst. The flare is classified as M6.1 and started at 07:29:00 UT and reached peak intensity at 07:43:00 UT

The speed of the CME was 590 km/s. Figure 5 shows the difference image of the CME obtained by the LASCO instrument on board the Solar and Hemispheric observatory (SOHO). No type II radio bursts were reported by the WIND/WAVES satellite in the interplanetary medium for this multiple type II radio bursts observed in the meter - decameter wavelengths. Table 1 shows the timing information of the multiple type II radio bursts and associated events.

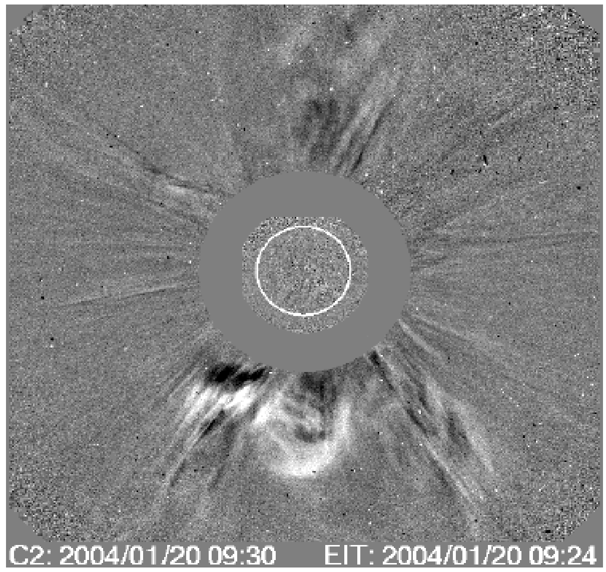

Figure 5. Difference image taken at 09:00 UT (frame at 09:00 UT has its previous frame subtracted) of the CME event observed with the LASCO C2 coronagraph on January 20, 2004

Table 1. Timing information of multiple type II radio bursts and associated solar activities

Category	Time in UT	
	First	Second
Burst start	07:40	07:50:00
GOES X-ray flare start	07:29:00	
GOES X-ray flare peak	07:43:00	
CME start	08:30:05 at 3.99 $R_\odot$	
CME onset at 1.5 $R_\odot$	07:40	
CME speed	590 km/s	

2.2. Data Analysis

For measuring the mean relative bandwidth, the fundamental of the multiple type II radio burst was divided into n equal time intervals (t_i to t_n). At each of these n time samples, the upper (f_u) and lower frequency (f_l) of the band split were measured. The mean relative bandwidth is given by

$$\frac{\Delta f}{f} = \sum_{i=1}^{n} \frac{f_u(t_i) - f_l(t_i)}{f_l(t_i)} \quad (3)$$

From the observed dynamic spectrum of the multiple type II radio bursts of January 20, 2004, we have measured the values of f_u and f_l at 10 different time samples during the life time of the type II_1 and at 5 different time samples for the type II_2 radio bursts. The mean values of relative bandwidth ($\frac{\Delta f}{f}$) for the type II_1 and type II_2 radio bursts respectively are 0.28 ± 0.03 and 0.20 ± 0.04. These values are in close agreement with the relative bandwidth value of 0.3 for 25 type II bursts reported by Mann et al., (1995, 1996). Using the equations 1 and 2, Alfven Mach numbers were calculated and their values respectively are 1.44 and 1.27 for the type II_1 and type II_2 radio bursts, suggesting that these shocks are weak in nature and the shock speed is greater than the Alfven speed. The value of the Alfven Mach numbers estimated by us lies close to the range (1.5 - 2.5) of values reported by Nelson & Melrose (1985). The mean of the measured values of the upper (f_u) and lower (f_l) frequencies were plotted against time for both the type II_1 and type II_2 bursts. The scattered points are approximated by a straight line and least square fits were made and is shown in the figure 6. The drift rates were estimated from the slope the curves. The drift rates for the type II_1 and type II_2 bursts respectively are -0.11 and -0.08 MHz/s. These values agree with the rule that the drift rate of type II radio burst increases with their starting frequency (Mann et al., 1995; Subramanian & Ebenezer, 2006). The characteristics of the multiple type II radio burst like the relative bandwidths, drift rates, the derived values of density jumps and the Alfven mach numbers are given in the table 2.

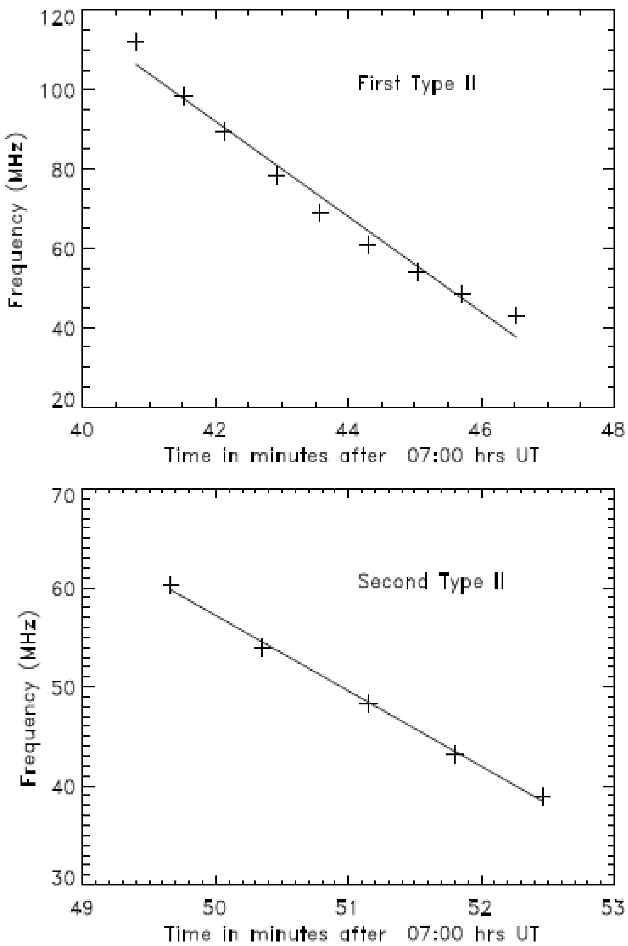

Figure 6. Scatter plot of the mean frequency and time for the first and second type II bursts of January 20, 2004

We have calculated the shock speeds of the type $II_1$and type II_2 bursts using the following relation (McConnell, 1980)

$$\frac{df}{dt} = -\left(8.7\times10^{-2}\right)v\times f\left[\ln\left(\frac{0.54f}{S\sqrt{M}}\right)\right]^2 \quad (4)$$

where V = v/c, v is the estimated shock speed and c is the velocity of light. Here f is the frequency of observations in MHz, s is the harmonic number (s = 1 here) and M is the density enhancement factor. The mean frequency of the type II1 and type II2 bursts in the present observations are 73 and 49 MHz According to Vrsnak et al (2004), the magnetic field strength derived from using the equations in section 2 is sensitive to the adapted value of the coronal density. Since the actual coronal density at the time of these observations is not known, we have used different densities in the calculation of the speed of type II_1 and II_2 radio bursts. We have used Newkirk's density model of the form

$$N_e = M\times 4.2\times10^4 x10^{\frac{4.32}{\rho}}$$ (ρ is measured in solar radii)

for the calculation of the speed of the type II radio bursts. We have used values of 1 to 5 for the density enhancement factor M in our calculations for the estimation of the shock speeds of type II radio bursts. Figure 7a shows the variation in the radial speed of type II_1 and type II_2 bursts for different density enhancement factors (DEF). From these values and the estimated Alfven mach No of 1.44 and 1.27 for the II1 and type II2 bursts, Alfven velocities are calculated and is shown in the figure 7b. Using the relation between the Alfven speed VA, the mean frequency of observation f and the magnetic field B (Dulk & Mclean, 1978) of the form

$$V_A = 1.9x10^4 x\frac{B}{f} \quad (5)$$

the magnetic field strengths were estimated. Figure 7c shows the variation of the magnetic field with DEF varying from 1 to 5 for mean frequencies (73 and 49 MHz) for the first and second multiple type II bursts. We have calculated the height at which 73 and 49 MHz radiation occur for DEF of 1 to 5 and varies from 1.35 to 1.73 solar radii for the first type II burst and 1.50 to 2.0 solar radii for the second type II radio burst.

Table 2. List of parameters of multiple type II radio bursts

Parameter	Value	
	Type II_1	Type II_2
Relative bandwidth Δf/f	0.28±0.03	0.20±0.04
Density jump N_2/N_1	1.64	1.44
Alfven Mach number M_A	1.44	1.27
Drift rate df/dt ($MH_{Z/S}$)	0.11	0.08
Mean frequency f(MH_Z)	73	49

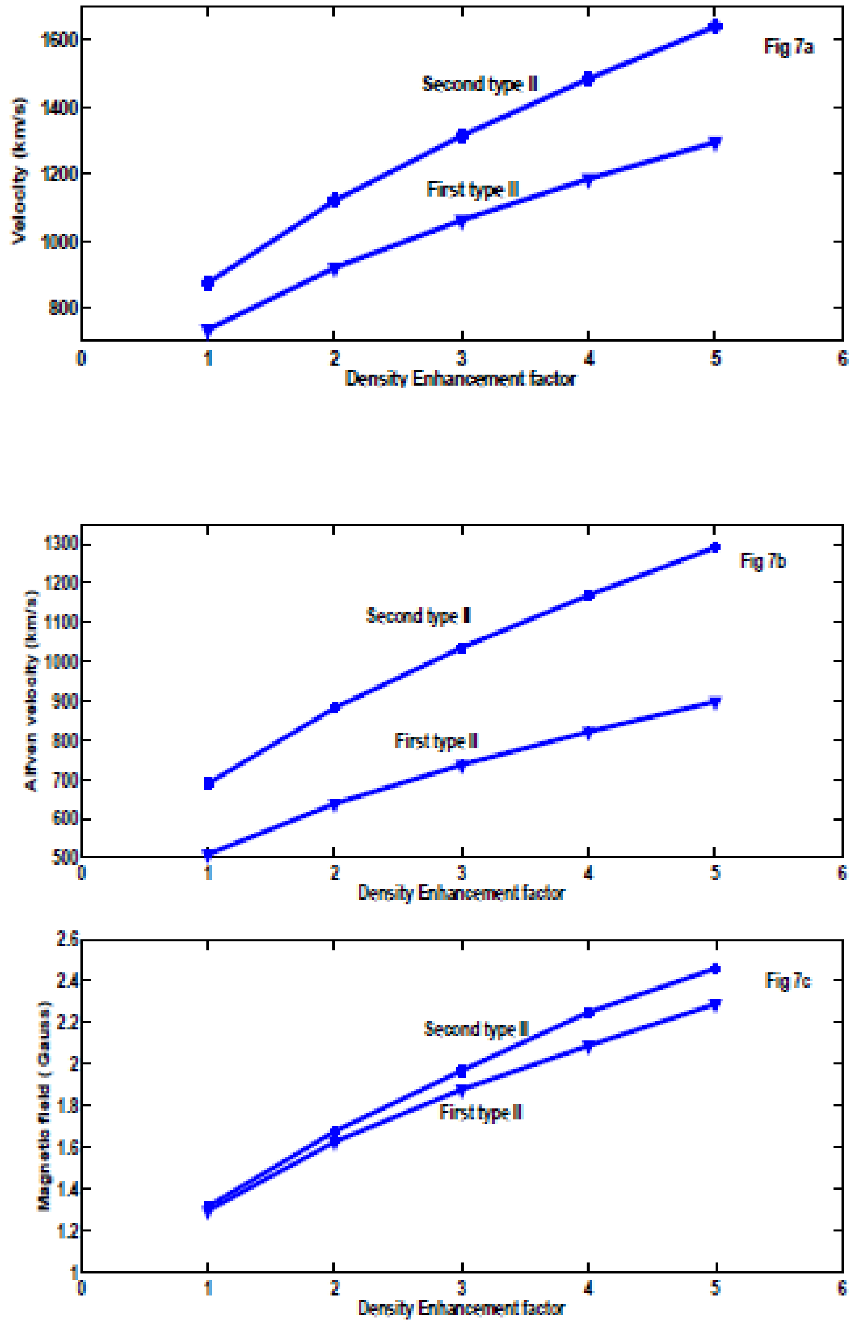

Figure 7. Variation of the type II bursts speeds (fig3a), Alfven speeds (fig 7b) and magnetic fields (fig7c) with density enhancement factor M

3. Discussions

Multiple Type II radio burst observed on January 20, 2004 was analyzed. Associated events clearly show that there was only a single flare and a CME. The timing of CME onset at 1.5 R_ at 07::40:UT is close to the start timing of the type II_1 burst. The closeness in the start timings of the flare and the multiple type II bursts suggests their close association. The estimated shock speed of the second type II radio burst was less than the first one for various densities we have used. The estimated Alfven Mach numbers for the first and second type II radio bursts respectively are 1.44 and 1.27 suggesting that these shocks are weak in nature. This is supported by the fact that these bursts have not been detected in the interplanetary medium by the IND/WAVES satellite. But only a type III burst has been observed by the WIND/WAVES satellite at the time of multiple type II bursts. One view is that multiple type II bursts are caused by a single flare (Gergely et al 1984) or a CME (Raymond et al 2000). According to this view that multiple type II bursts are caused by a single shock travelling through different coronal structures. Another view (Reiner et al 2001: Shanmugaraju et al 2005) is that two coronal shocks are generated from different sources; one burst is due to a flare and the other due to a CME. The scenario suggested by Cho et al. (2007) that multiple type II bursts are caused by a single shock travelling through different coronal structures like coronal streamers may be applicable in the present case since no multiple flares or CMEs are seen.

In the present observations we found that there was only a single flare and a CME associates with the multiple type II burst. The drifting stripes of type II bursts are interpreted a signature of coronal shock waves, the frequency of radio emission can be converted into emission heights of heights by adopting a coronal density model. Since the second type II burst occurs at a lower frequency compared to the first type II burst, the emission height of the second type II burst is more than the first type II burst for the density multiplications factor 1 to 5 used here. Since no type III burst is seen between the multiple type II bursts in the present observations, we can be sure that there is no CME-streamer inter-action and the second burst is not generated by the interaction between the CME and the helmet streamer (Reiner et al 2003; Vourlidas et al (2003); Cho et al 2008 Mann et al., 1996).

The derived Alfven speed and the hence the value of the magnetic field were found to increase with density. For density factors of 1 to 5 in the Newkirk's density model, the derived values of the magnetic field were found to vary from 1.3 to 2.29 gauss for the II_1 radio burst and from 1.32 to 2.46 gauss for the II_2 radio burst. These values are in close agreement with the value of the magnetic field reported by Smerd et al., (1974), Dulk and McLean (1978), Kruger & Hildebrandt(1993), and Vrsnak et al., (2001) at these heights. Radio heliographic observations by Robinson et al., (1985) have shown that often type II radio bursts do not propagate radially which means that shock velocity is underestimated. If θ is the angle between the radial density gradient and the direction of the source motion, the true velocity is given by $V_{true} = V_{observed}/\cos\theta$. The same speed is obtained for 5 times the Newkirk's density with angle θ= 47 degrees and 3 times Newkirk's density with θ of zero degrees. Therefore, the assumption of radial motion of type II radio bursts will also contribute to errors in the estimation of the magnetic field. Since the derived magnetic field from the first and second type II bursts are nearly same in our case, the first type II burst may be generated in the nose of the CME and the second type II bursts at the flanks of the CME. Another possibility is the dimming of corona. Coronal dimming is a depletion of the brightness in the low corona and is associated with CME and is attributed to mass loss in the corona (Howards et al 2003). The mass loss and the lower density may be the reason for generation the second type II burst.

4. Conclusions

We have used the relative bandwidth and drift rate properties of type II doublet radio bursts to derive magnetic field strength and the gradient of the magnetic field in the outer corona. The magnetic field strength was derived for different densities. The associated solar activities were described. The main results are

1. The relative The relative bandwidth for the first and second type II bursts respectively are 0.28 and 0.20.
2. The Alfven Mach numbers for the first and second bursts respectively are 1.64 and 1.44.
3. The mean frequency of the first type II burst is 73 MHz and the same for the second burst is 49 MHz.
4. The derived magnetic field varies from 1.30 to 2.24gauss for the first burst and 1.32 to 2.46 gauss for the second burst for Newkirk's density with density enhancement factors 1 to 5.

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