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Estimation of Magnetic Field Strength from Enhanced Solar Radio Emission

S. B. S. S. Sarma

Radio Science Division, National Physical Laboratory,
New Delhi 110 012, India.

Abstract

The manifestation of solar activity on radio noise records at 28·6 MHz is discussed with special emphasis on Type-I noise storms and the associated coronal magnetic fields above the active regions in time. Magnetic fields are estimated, assuming that the Type-I radio emission at decametre wavelengths is due to shock waves, by making use of the observed shock velocity. The results are comparable with the existing estimates.

1. Introduction

Solar radio emission originates in layers of the solar atmosphere ranging from the chromosphere to the corona. These radio waves are not important for the release or transport of energy in the Sun but appear to be very effective in providing diagnostics for the solar plasma, especially with respect to the magnetic field in the corona and the location of the release of nonthermal energy. Hence, observation of the Sun at radio wavelengths provides useful information on magnetic fields in the solar atmosphere. Time series observations made at metre and decametre wavelengths give information on the magnetic fields in the corona and reflect long-lasting nonthermal energy release in the corona of an active region. It is significant that the lifetime of these sources is 2 to 5 days and they demonstrate rather good stability of emission.

The present paper deals with estimates of the magnetic fields in the solar corona using Type-I noise storm measurements of cosmic radio noise records at Bangalore at 28·6 MHz; therefore, the fields correspond to a slowly varying active Sun.

2. Experimental Set-up

The experimental set-up consists of a broad-beam antenna system, a low-noise receiver and data processing system. The antenna has a broadside array of three wavelengths along the N–S direction and five wavelengths in the E–W direction. A schematic representation of the antenna array is shown in Fig. 1. The Sun is overhead at Bangalore during the last week of April and in the third week of August during the course of its movement across the sky.

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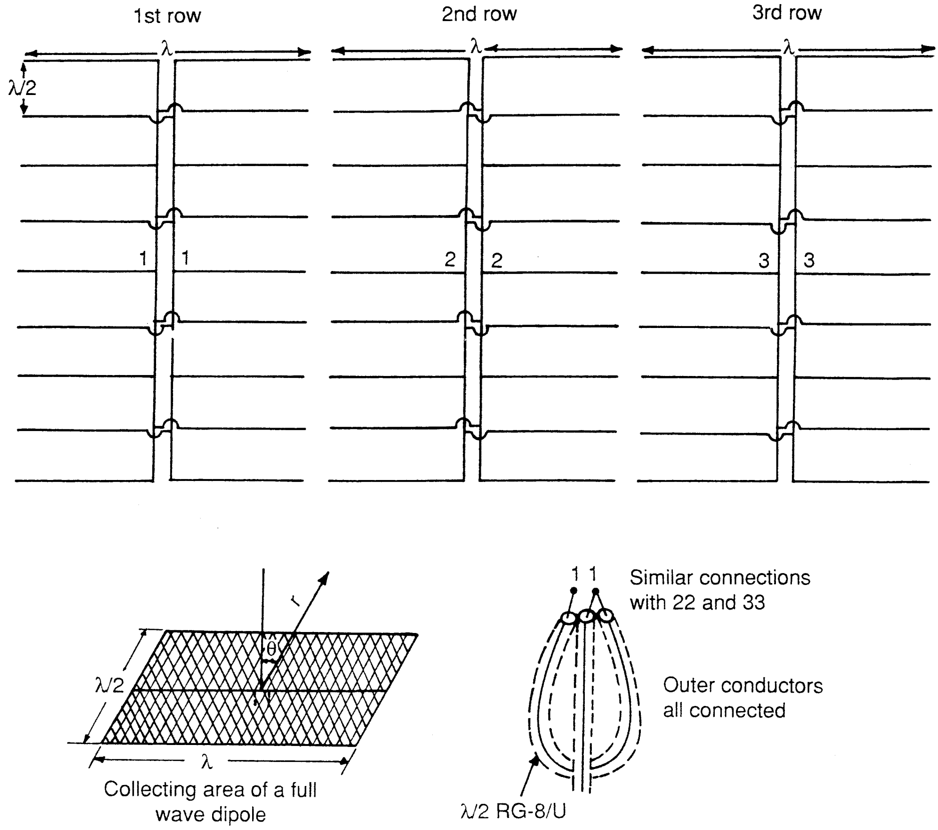

Fig. 1. Schematic representation of the antenna array.

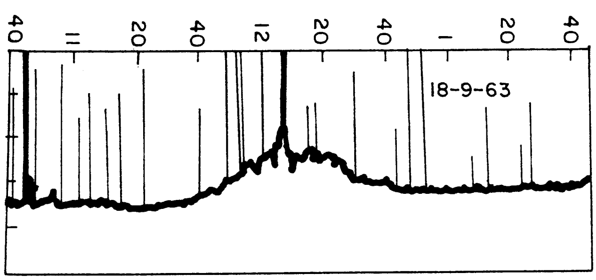

Fig. 2. Typical time profile of the cosmic radio noise during the Type-I solar noise storm on 1963 September 18.

3. Observations

At the Indian Institute of Science in Bangalore (Lat. 12°58′N, Long. 77°35′E), time series of Type-I solar continuum radiation have been recorded on several occasions at 28·6 MHz. The recordings from 17 noise storm periods were selected for analysis. An example of a typical time profile of a noise storm is shown in Fig. 2. It was difficult to discriminate between a chain of bursts and a random statistical clustering of individual bursts. The noise storms which were analysed in the present investigation constitute a well-defined group and are identified on the records without serious ambiguity. The features investigated were the inferred radial velocities, the intensity of the magnetic field and the electron density. The measurements at this frequency relate to storms of various duration and intensity which occurred during the observational period of July 1962 to April 1963. In all cases the flux density variation showed an interesting smooth exponential decay with approximately the same decay constant. Only those flares which occurred when the Sun was within $\pm 53°$ of the zenith were recorded, corresponding to a period between 0830 to 1530 L.T.

4. Results and Conclusion

We have re-evaluated the sources of the above data and tried to improve upon the estimates of magnetic field by adopting the latest plasma concepts, since the theories of these noise storms were uncertain at the time of the data collection. If we assume that the Type-I bursts originate at the fundamental plasma frequency, the electron density N (cm^{-3}) is obtained from $f_{\rm P}$ (MHz) by the equation $N = 1\cdot 24 \times 10^4\, f_{\rm P}^2$. One can then estimate the height of the source using a given density model. We have adopted the '2×Newkirk' (1961, 1967) model of coronal streamers. It was observed that at the present observing frequency, the total number of electrons involved is of the order $1\cdot 26 \times 10^{13}$ m^{-3}, and the height at which these Type-I storms originated is $2\cdot 0 R_\odot$, where $R_\odot$ is the solar radius. In the present case, the radial velocity of the Type-I storm was in the range 900 to 450 km s^{-1}, which is close to the 800 km s^{-1} reported by Elgaroy and Ugland (1970). It is widely accepted that the radial velocity of the disturbance is equal to the Alfvén velocity (Weiss 1965) $V_{\rm a} = 2 \times 10^4\, H/f_{\rm P}$ km s^{-1}, where H is in Gauss (1 G $\equiv 10^{-4}$ T) and $f_{\rm P}$ in MHz. Newkirk (1967, 1971) estimated the magnetic field strength in the solar corona, while Dulk and McLean (1978) re-examined the sources and improved upon the above estimates by eliminating outmoded, incorrect and inapplicable concepts of plasma physics. Kakikuma and Swarup (1972) have studied the slowly varying component and found that the Type-I storms are the only phenomena that can be used to estimate the magnetic fields in the above regions without any flare association. In a similar attempt, Wild and Tlamicha (1964) estimated the coronal magnetic field by making use of Type-I noise storm spectral characteristics. They postulated that the shock waves could generate Type-I bursts, estimated the radial field with an exponential decay and reported that there is no necessity of subjecting the Type-I data to spectral analysis. Gopalswamy *et al.* (1986) derived the coronal magnetic fields at various heights based on Type-I observations (from various existing data), assuming that the emission originates at the local plasma frequency level. The most interesting feature of the Type-I bursts is their narrow bandwidth and, as such, the shock travels only a small distance in the corona compared with the coronal scale height.

Gopalswamy *et al.* (1986) used Type-I burst data covering 256 to 40 MHz, whereas we have extended the observations down to 28·6 MHz. Utilising the observed smooth decay (Sarma 1965) of the flux density, we have estimated the magnetic field strength during the evolution of the active region over time, assuming that the emission is at the local plasma frequency.

From the present investigations, the observed mean intensity of the magnetic field of $0\cdot 3$ G, corresponding to the $28\cdot 6$ MHz plasma level, is comparable to:

(1) the value of $0\cdot 35$ G given by the R^{-2} model suggested by Behannon (1976);

(2) the magnetic field suggested by Harvey (1969) which, when extended to $2R_\odot$, is about $0\cdot 25$ G;

(3) the value inferred by Dulk and McLean (1978) from their empirical formula $B = 0\cdot 5(R/R_\odot - 1)^{-1\cdot 5}$ G, which comes to $0\cdot 5$ G; and

(4) the value suggested by Gopalswamy *et al.* (1986) from their empirical formula $B = 0\cdot 41(R/R_\odot - 1)^{-0\cdot 89}$ G, which gives $0\cdot 41$ G.

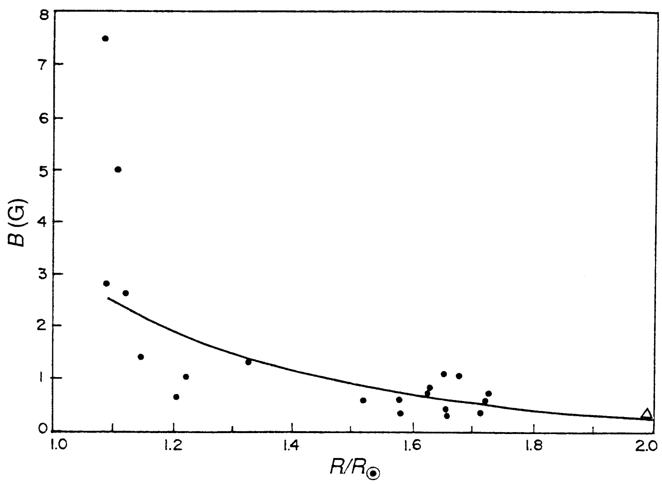

Fig. 3. Magnetic field B versus radial distance (in units of the solar radius $R_\odot$). The curve was fitted using a least-squares analysis. The open triangle (bottom right) is the present data.

We have utilised the existing data on Type-I storms obtained by various investigators (Elgaroy and Ugland 1970; Wild and Tlamicha 1964; De Groot 1966; De Groot *et al.* 1976; Karlicky and Jiricka 1981; Tlamicha 1982; Aurass *et al.* 1981; Aubier *et al.* 1978), along with the present data, to reanalyse the variation of magnetic field strength with height. An exponential curve was fitted by using a least-squares analysis and is shown in Fig. 3. The data refer to different active regions observed at varying times and with a variety of instruments. From Fig. 3 an empirical formula for the observed magnetic field can be written as

$$B = 41\cdot 26 \exp(-2\cdot 56 R/R_\odot)\,,$$

where B is in Gauss and $R/R_\odot$ is the height in the solar corona expressed in solar radii. In summary, the magnetic field B in the source region is about $3\cdot 2$ G, compared with the value 5–10 G reported by Elgaroy and Ugland (1970). Further, the observed value of $0\cdot 3$ G for the field strength at the $28\cdot 6$ MHz level compares very well with other model values, as indicated above, and gives some idea of the accuracy of the present estimates.

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