MAGNETIC FIELD STRENGTH ESTIMATION IN SYNCHROTRON RADIATION SOURCES

A.-H. ZHOU
United Laboratory for Radio Astronomy, Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing, China

(Received 19 April, 1994; accepted 1 July, 1994)

Abstract. In this paper a method of estimating the magnetic field strength, \( B \), in a homogeneous microwave burst source with simplified expressions for the synchrotron radiation is presented. An approximate formula of the magnetic field is obtained using the method. Once the magnetic field is estimated the total number of energetic electrons along the line of sight \( N_L \) can be estimated also. The errors of \( B \) and \( N_L \) have been given. It is found that this method is useful for semiquantitative investigations of models of radio burst sources.

1. Introduction

Microwave, hard X-ray and \( \gamma \)-ray emissions provide the most direct evidence available for the role of energetic electrons in solar flares. Observations of these impulsive emissions yield complementary diagnostics for the physical characteristics of their source regions. Microwaves are produced predominantly by interactions of electrons with solar magnetic fields. In a theoretical perspective, microwave spectroscopy should have the potential ability to diagnose the behavior of energetic electrons and magnetic fields in a burst source. In fact, it seemed to be impossible to invert the magnetic field from the gyrosynchrotron radiation or synchrotron radiation until the simplified expressions of the two types of radiation were given by Dulk and Marsh (1982) and Dulk (1985), but either additional assumptions or data are usually necessary to separate the properties of magnetic fields from those of the electron distribution (e.g. Batchelor et al., 1984; Gary, 1985; Kosugi et al., 1988; Zhou, 1992; Bastian et al., 1992; Zhao, 1993). In this paper a method to estimate directly the magnetic field strength, \( B \) and the total number of energetic electrons, \( N_L \), is presented and their accuracies of the estimated values of \( B \) and \( N_L \) are discussed. It is possible that hard X-ray or \( \gamma \)-ray and microwave emissions could be produced by the energetic electrons with the same power-law distribution, and their sites of sources could be very close to each other. So the value of the magnetic field strength estimated by the method may represent that of the hard X-ray or \( \gamma \)-ray sources.

2. Synchrotron Radiation from Power-Law Electrons

For a distribution of electrons that is isotropic in pitch angle and follows a power law in energy above \( E_0 \):

expressions for the emissivity and for frequency of peak flux density are, respectively, given by Dulk (1985) for $2 \leq \delta \leq 5$

$$\frac{\eta_\nu}{BN} \approx 8.6 \times 10^{-24}(\delta - 1) \sin \theta \left[ \frac{0.175}{\sin \theta} \left( \frac{E_0}{1 \text{ MeV}} \right)^{-2} \frac{\nu}{\nu_B} \right]^{-(\delta - 1)/2},$$  

$$\nu_p \approx 3.2 \times 10^7 \sin \theta \left( \frac{E_0}{1 \text{ MeV}} \right)^{(2\delta - 2)/(\delta + 4)} \left[ 8.7 \times 10^{-12} \frac{\delta - 1}{\sin \theta} NL \right]^{2/(\delta + 4)} \times B^{(\delta + 2)/(\delta + 4)},$$

where $\delta$ and $N$ are, respectively, the electron energy spectrum index and the number density of nonthermal electrons with $E > E_0$, $\theta$ is the viewing angle, $L$ the dimension of the source along the line of sight, $\nu$ is the observing frequency and $\nu_B = 2.8 \times 10^6 B$ is the cyclotron frequency.

For synchrotron emission, $\nu_p$ depends very strongly on the magnetic field. So we try to invert directly the magnetic field from the frequency of peak flux density, $\nu_p$. From expression (3) we can see that if $\nu_p$, $\delta$ and $NL$ are given, the magnetic field $B$ can be derived. The parameters $\nu_p$ can be obtained directly from microwave multifrequency observations. The electron energy spectrum index $\delta$, while that at the optically thin high frequencies in the synchrotron radiation case is (Dulk, 1985)

$$\alpha = -\frac{(\delta - 1)}{2},$$

when we define the observing flux density spectrum as

$$S \propto \nu^\alpha.$$  

So the matter is how to express the term $NL$, which is the total number of nonthermal electrons along the line of sight $N_{\text{total}}$. This term is usually estimated under some additional assumptions about the radio source or data. Now we will give an analytical expression of the term of $NL$ that is related to emission coefficient to invert the magnetic field strength.

3. Inversion of Magnetic Field Strength

In the homogeneous and optically thin ($\tau_\nu \ll 1$) sources, the brightness temperature $T_b$ reduces to (Dulk, 1985)

$$T_b = T_{\text{eff} \nu} = \frac{c^2}{k_B \nu^2} \eta_\nu L.$$