MICROWAVE EMISSION FROM A SUNSPOT

I. Implications for the Sunspot Magnetic Structure

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Abstract. From the gyroresonance brightness temperature spectrum of a sunspot, one can determine the magnetic field strength by using the property that microwave brightness is limited above a frequency given by an integer-multiple of the gyrofrequency. In this paper, we use this idea to find the radial distribution of magnetic field at the coronal base of a sunspot in the active region, NOAA 4741. The gyroresonance brightness temperature spectra of this sunspot are obtained from multi-frequency interferometric observations made at the Owens Valley Radio Observatory at 24 frequencies in the range of 4.0–12.4 GHz with spatial resolution 2.2″–6.8″.

The main results of present study are summarized as follows: first, by comparison of the coronal magnetic flux deduced from our microwave observation with the photospheric magnetic flux measured by KPNO magnetograms, we show that the o-mode emission must arise predominantly from the second harmonic of the gyrofrequency, while the x-mode arises from the third harmonic. Second, the radial distribution of magnetic fields $B(r)$ at the coronal base of this spot (say, 2000–4000 km above the photosphere) can be adequately fitted by

$$B(r) = 1420(1 \pm 0.080) \exp \left[-\left(\frac{r}{11.05''(1 \pm 0.014)}\right)^2\right] \text{G},$$

where $r$ is the radial distance from the spot center at coronal base. Third, it is found that coronal magnetic fields originate mostly from the photospheric umbral region. Fourth, although the derived vertical variation of magnetic fields can be approximated roughly by a dipole model with dipole moment $1.6 \times 10^{30} \text{erg G}^{-1}$ buried at 11000 km below the photosphere, the radial field distribution at coronal heights is found to be more confined than predicted by the dipole model.

1. Introduction

There have been many attempts to determine the strength and configuration of coronal magnetic fields over solar active regions by making use of the observed microwave emission from the regions, which are otherwise too transparent to many forms of radiation available in ground-based observations. Previous efforts along this line were made in two ways. One is to do a model-fit to the field configuration which can reproduce the spatial distributions of microwave brightness over the active region imaged at one or a few frequencies. The other approach is to use the microwave spectrum to exploit its sensitive dependence on the magnetic field strength.

The first approach is made in a number of studies, where very large arrays such as WSRT or VLA are used to yield high-spatial resolution microwave maps (e.g., Kundu, Becker, and Velusamy, 1974; Kundu and Alissandrakis, 1984; Lang, Wilson, and Gaizauskas, 1983; Chiuderi Drago, Alissandrakis, and Hagyard, 1987). Often, observations in different regimes such as X-ray and UV were performed simultaneously to provide the physical parameters required for the model-computation (e.g., Schmahl
et al., 1982; Shibaski et al., 1983). The second approach permits a more direct determination of the coronal field strength, but is limited to a few telescopes such as RATAN-600 and the array at Owens Valley Radio Observatory (OVRO) which are capable of observing at many frequencies (e.g., Akhmedov et al., 1982; Krüger et al., 1986; Hurford and Gary, 1986). Obviously, a more complete implementation of microwave observation as an independent diagnostic tool would be possible if both spatial and spectral resolutions were achieved at the same time.

We report, in this paper, such an implementation made possible by the multi-frequency, interferometric observation of a simple sunspot with the OVRO Solar Array. The basic strategy of this paper is similar to that of Hurford and Gary (1986) in that the spectral behavior of microwave brightness temperature and source size are used as a means to determine the coronal magnetic fields. The difference is that this approach aims at empirical determination of the coronal magnetic field as a function of radial distance while Hurford and Gary (1986) sought a dipole magnetic field model by which the observed microwave spectrum can be reconstructed. For this particular purpose, we choose data obtained from microwave observations of the active region, NOAA 4741, at OVRO on 1986 August 2. These data have several distinct advantages over previous ones gathered at OVRO for many years. Owing to the fact that solar activity was at its lowest at that time, NOAA 4741 was the only active region on the solar disk, which case avoids the problem of confusion by other sources. We have observations over many days while the region transmitted the solar disk, which will be presented in a second paper (Lee, Gary, and Hurford, 1993). This paper concentrates on the unique information that can be gained when the region is nearest the disk center and thus the projection effects can be ignored. The active region was an exceptionally simple, single round sunspot on both white-light images and magnetograms, which allows us to assume radial symmetry to the problem. The plan of this paper is as follows. In Section 2, we describe the observational techniques. In Section 3, we identify the radiation mechanism and discuss its diagnostic potential for detecting the magnetic field strength. In Section 4, we present the procedure and result of the coronal magnetic field determination. Finally, our approach and results are discussed in Section 5.

2. Observation

2.1. Source

The source region, NOAA 4741, passed the central meridian on 1986 August 2 at a latitude of N 10°. In Figure 1, the white-light picture of this spot is shown. Superimposed contours are the levels of magnetic field strength taken from KPNO magnetogram. The spot has negative magnetic polarity, but we will use its absolute value throughout this paper. No significant activity was observed during the whole day and thus we attempt mapping of this active region using Earth-rotation synthesis with the three-element interferometer at OVRO to get the spatial information on the microwave emission.