MICROWAVE EMISSION ABOVE STEADY AND MOVING SUNSPOTS

F. CHIUDERI DRAGO*
Observatoire de Paris, Meudon, DASOP, 92195 Meudon Principal CEDEX, France

C. ALISSANDRAKIS
Department of Physics, University of Athens, GR 15783, Athens, Greece

and

M. HAGYARD
NASA Marshall Space Flight Centre, AL 35812, U.S.A.

(Received 26 June, 1987)

Abstract. Two-dimensional maps of radio brightness temperature and polarization, computed assuming thermal emission with free-free and gyroresonance absorption, are compared with observations of active region 2502, performed at Westerbork at $\lambda = 6.16$ cm during a period of 3 days in June 1980. The computation is done assuming a homogeneous model in the whole field of view ($5' \times 5'$) and a force-free extrapolation of the photospheric magnetic field observed at MSFC with a resolution of $2'' \times 34$. The mean results are the following:

(a) A very good agreement is found above the large leading sunspot of the group, assuming a potential extrapolation of the magnetic field and a constant conductive flux in the transition region ranging from $2 \times 10^6$ to $10^7$ erg cm$^{-2}$ s$^{-1}$.

(b) A strong radio source, associated with a new-born moving sunspot, cannot be ascribed to thermal emission. It is suggested that this source may be due to synchrotron radiation by mildly relativistic electrons accelerated by resistive instabilities occurring in the evolving magnetic configuration. An order-of-magnitude computation of the expected number of accelerated particles seems to confirm this hypothesis.

1. Introduction

High-resolution observations of solar active regions in the microwave range have shown several types of sources which are all associated to particular configurations of the magnetic field. Sunspot associated sources have been observed extensively in the 2–6 cm range (e.g., Kundu and Alissandrakis, 1975; Kundu et al., 1977; Pallavicini et al., 1979; Lang and Willson, 1982; Akhmedov et al., 1982, 1983; Chiuderi-Drago et al., 1982; Shibasaki et al., 1983; Krüger et al., 1986). These sources are best observed around 6 cm where their peak brightness temperature is a few million degrees; at shorter wavelengths their brightness decreases, while at longer wavelengths they are obscured by other types of emission.

The emission of sunspot associated sources is attributed to thermal gyroresonance from the second and third harmonics of the gyrofrequency (Zheleznyakov, 1962; Kakinuma and Swarup, 1962). Model computations assuming a plane-parallel tempera-
ture and density structure of the atmosphere above the spot and either an extrapolation of the photospheric magnetic field (Alissandrakis et al., 1980), or an axially-symmetric theoretical magnetic field model (Gelfreikh and Lubyshev, 1979; Alissandrakis, 1980; Krüger et al., 1985) have succeeded in reproducing the principal characteristics of the total intensity and circular polarization maps.

More recent observations with higher angular resolution showed deviations from plane-parallel structure. The presence of cool material above the umbra was inferred in some cases (Alissandrakis and Kundu, 1982; Strong et al., 1984), which may also explain the lack of sunspot associated emission in some active regions (Kundu et al., 1981; Felli et al., 1981). Kundu and Alissandrakis (1984) observed distinct sources above a sunspot penumbra which they attributed to local density enhancements, while Alissandrakis and Kundu (1984) interpreted differences between observed and computed maps of sunspot associated sources as evidence of inclination of the axis of symmetry of the magnetic field or of variations of the conductive flux which affects the temperature structure.

Sunspot associated sources are not always the brightest features in active regions. Several observations at 6 cm have shown strong emission above the principal neutral line of the active region (Kundu and Velusamy, 1980; Kundu et al., 1981; Alissandrakis and Kundu, 1982; Schmahl et al., 1982; Akhmedov et al., 1986). Such sources are associated with active region filaments (Kundu et al., 1977; Kundu and Velusamy, 1980; Alissandrakis and Kundu, 1982) or with arch filament systems (Kundu et al., 1981; Kundu and Alissandrakis, 1984) and with X-ray loops (Schmahl et al., 1982; Strong et al., 1984). The origin of such sources is not well understood (Kundu et al., 1977).

In addition to the sunspot and neutral line associated sources, the radio emission of active regions at short cm wavelengths has components associated with local enhancements of the plage magnetic field and a halo-type component associated with the chromospheric plage (Kundu et al., 1977). At longer wavelengths (around 20 cm) the emission is dominated by the plage component (Chiuderi-Drago et al., 1977; Dulk and Gary, 1983) and/or coronal loops (Lang et al., 1982); the connection of the latter type of structure with sunspot associated sources at shorter wavelengths was beautifully demonstrated in the observations of Gary and Hurford (1987).

During the period of June 13 to 16, 1980 Shibasaki et al. (1983, hereafter referred to as Paper I) observed for the first time a 6 cm source which was associated with the formation of a new spot. The spot formed by merging of pores and new emerging flux between the preceding sunspot and the neutral line of active region 2502 (Hale 16898), during the first half of June 14; subsequently it moved towards the preceding spot of the region with which it merged by June 16. The associated radio emission had a brightness temperature $T_b \geq 4 \times 10^6$ K, about a factor of two larger than the source associated with the preceding spot. Shibasaki et al. (1983) interpreted the emission from the steady source in terms of the gyroresonance process and they suggested non-thermal emission for the moving spot. However, due to the lack of photospheric field observations no model computations were done in Paper I.

In this paper we use observations of the photospheric magnetic field from Marshall