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CORONAL MAGNETIC FIELDS FROM THE EFFECT OF THE DOUBLE INVERSION OF CIRCULAR POLARIZATION OF RADIO EMISSION

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ABSTRACT We present preliminary results of radio observations of the Sun with the Panoramic Analyzer of the Spectrum (21 channels in 1.8 - 8.2 cm wavelength range) of the radio telescope RATAN-600. Observations on 1992 January 9 - 10 have shown double inversion of the sign of a local source through the microwave wavelength range with fine spectral structure. This phenomenon can be treated as a result of mode coupling when the electromagnetic wave crosses two regions of quasi-transverse propagation (QT-region). Using this treatment we have found the strength of the coronal magnetic field at a number of points in the corona above an active region. The results also imply that trans-equatorial coronal arches affect the structure of magnetic fields at heights of about $3 \cdot 10^{10}$ cm with $B \sim 5$ - 10 G.

INTRODUCTION

Time and wavelength changes of the inversion of the circular polarization of sunspot-associated radio sources have been investigated previously. It has been found that the main reason for the inversion is propagation in quasi-transverse magnetic fields of the solar corona. So far, however, there are only observations of one change of the sign of polarization throughout microwave range for some sources in an active region (AR) (Peterova & Akhmedov 1974).

Here for the first time we present results of radio observations of double inversions of the polarization of sunspot-associated sources. Also we demonstrate a significant increase of information about the coronal magnetic structure from model simulations that account for the effect of the double inversion.

RADIO OBSERVATIONS

Observations of both the intensity and circular polarization were carried out at 21 wavelengths in the range 1.8 - 8.2 cm using the new Panoramic Analyzer of the Spectrum (PAS) of the RATAN-600 radio telescope. The one-dimensional spatial resolution was 15" at the shortest wavelength.

Figure 1 presents radio scans of the solar disk on 1992 January 9 in circularly polarized emission. Note the double inversion of the polarization of the sunspot-associated source # 1 (Boulder AR 6996) between 4.73 and 5.26 cm, and between 5.26 and 6.50 cm. On 1992 January 10 the first change of the sign happened at shorter wavelengths (3.86 - 4.15 cm), while the second one was between 5.26 - 6.50 cm. All three sources above are associated with large sunspots (Boulder AR 6996, 6998, and 7006). The excess of the extraordinary mode of radio emission at the shortest wavelengths agrees with the polarity of the photospheric magnetic field of the corresponding sunspot. This emission is generated by the thermal cyclotron mechanism.

MODEL ANALYSIS

The inversion phenomenon seems to agree with an explanation based on the coupling theory of the propagation of microwaves in a region of quasi-transverse magnetic fields in the solar corona. In such a case, the degree of circularly polarized radio emission, $P = -1$, should be transformed in a QT-region according the following law (Zheleznyakov 1970):

$$P = 1 - 2 \cdot \exp(-2\delta_0),$$

where

$$\delta_0 \approx 10^{-25} \cdot N \cdot B^3 \cdot L \cdot \lambda^4.$$

All the quantities are in cgs units, λ is the wavelength of the emission, L is the characteristic length of magnetic field divergence, N is the electron density and B is the strength of the transverse magnetic field. The observational facts below are in accord with the interpretation based on the coupling theory:

— the sign and the degree of circular polarization strongly depend on the wavelength of the microwave emission (the polarization of the source inverts within the range of $\Delta\lambda/\lambda \approx 10\%$);

— motion of the local source due to solar rotation in the western solar hemisphere causes the wavelength of the first inversion to decrease (cf. Gelfreikh, Peterova, & Ryabov 1987).

Due to an exponential dependence of the polarized radio flux on δ_0, the inversion effect is very sensitive to the strength of the magnetic field in a QT-region. That is essential for accurate measurements of B. The values of coronal electron density N, and the scale of magnetic field divergence L, which should be chosen *a priori*, are less critical.

An additional opportunity to evaluate the field strength of B is gained by model simulation. To get agreement of a model simulation with radio scans observed at the RATAN-600, we have varied the depths of submergence of model dipoles beneath the photosphere. The best fit was considered to be a model of the coronal magnetic structure above an AR.

In this way, it was found that the first inversion (at shorter wavelengths) requires coronal magnetic fields of 15 to 50 G at heights of $5 \cdot 10^9 - 2 \cdot 10^{10}$ cm. Additionally, one needs to include trans-equatorial coronal arches in the model with a characteristic size of about $(2-3) \cdot 10^{10}$ cm and a magnetic field of 5 - 10 G to explain the second inversion (at a longer wavelength). The QT-region of

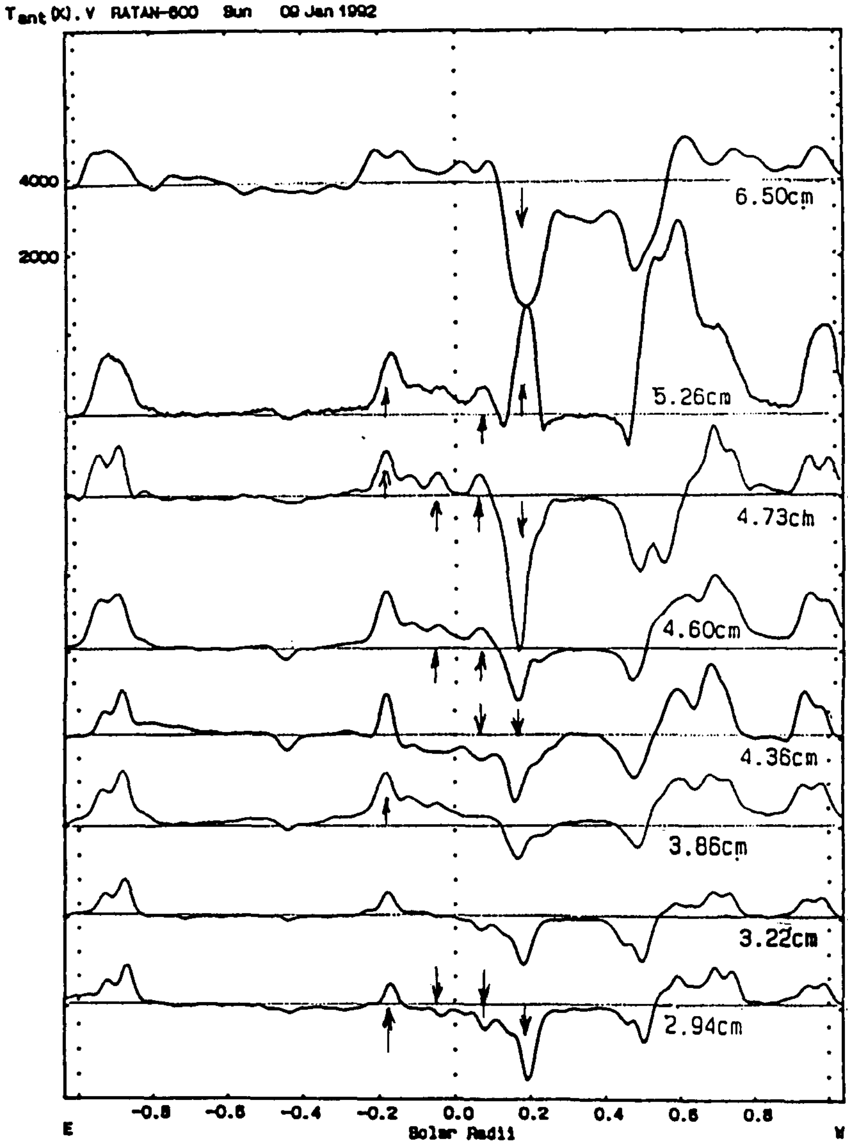

Fig. 1. Solar scans of circular polarization made with the PAS on the RATAN-600 on 1992 January 9. The arrows indicate locations where the sign of the circular polarization changes with wavelength.

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the trans-equatorial arch system was situated to the southwest, and the lower coronal arch system to the northeast of sources # 1 and # 2.

DISCUSSION

The precision of the measurements of coronal magnetic field strength by this method depends mainly on the determination of the inversion wavelength. Using the new spectrometer, PAS, we achieve an accuracy of about 10%. On the other hand, the accuracy of sunspot positions restricts the accuracy of the model evaluation of the height above the photosphere of the QT-region, where the coronal magnetic field is measured. When we treat the case of double inversion the accuracy is higher. The thickness of QT-region is usually about 10^8 cm, thus the integration layer of the measured B is sufficiently small.

While modeling coronal magnetic fields, the geometry of the so-called inversion screen is of special interest. The inversion screen (IS) is a surface where the propagation angle $\alpha = 90°$ and the circular polarization of the observed radio emission transforms according to the law above. We summarize the main features of the IS as follows:

1. The lower border of the IS corresponds with the neutral line of the longitudinal component of the photospheric magnetic field.
2. All neutral points of the coronal magnetic field ($B = 0$) lie on the IS.
3. Observations of the double inversion of circular polarization present an opportunity to measure the magnetic field on the IS in the vicinity of the coronal neutral point (Ryabov & Spektor 1983).

The observations of the phenomena of inversion of circular polarization of microwave emission of AR using PAS lead us to following conclusions:

— the double inversion of circular polarization of solar microwave emission is not rare (three cases per 100 days of observations);

— the Panoramic Analyzer of the Spectrum of RATAN-600 is an effective tool to measure magnetic fields in the solar corona at heights up to $3 \cdot 10^{10}$ cm above the photosphere simultaneously at several coronal locations;

— the vicinity of neutral points of the coronal magnetic field in principle may be investigated using the effect of double inversion of polarization of microwaves.

REFERENCES

Gelfreikh, G.B., Peterova, N.G., & Ryabov, B.I. 1987, Solar Phys., 108, 89

Peterova, N.G. & Akhmedov, Sh.B. 1974, Soviet Astron., 17, 768

Ryabov, B.I. & Spector, A.R. 1983, Publ. Debrecen Heliophys. Obs., 5, 323

Zheleznyakov V.V. 1970, Radio Emission of the Sun and Planets, (New York: Pergamon Press)