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Different modes for spectropolarimetric measurements

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Abstract. Spectropolarimetric methods used at the Sayan Solar Observatory for measuring magnetic field strengths are described. The spectropolarimeter consists of a polarization splitter and a ferroelectric liquid crystal (FLC) modulator, allowing for several longitudinal H measurement modes. The report discusses advantages and disadvantages of modulation-based and modulationless measurements using ordinary slow CCD cameras. In some cases combined variants appear to be preferable.

Even though there are many various techniques to measure the solar magnetic field, the underlying ideas often cannot be implemented by means of what is available to the observer. For example, to measure longitudinal magnetic field one should obtain information about both sigma components of Zeemans splitting. Due to the Earth's atmosphere, the spectrograph slit is exposed to different objects at different time moments. The measurement precision directly depends on whether the conditions for achieving information on the polarized component are the same. To provide for the conditions to be the same two main principles are usually obeyed: 1) temporal modulation, and 2) space separation of two spectra polarized in different ways. The paper discusses optical schemes based on each of these techniques and their combination. The observations were made using the horizontal solar telescope at the Sayan Solar Observatory (mirrors 800 mm, the main mirror 900 mm, focal length 20 m, grating 240×240 mm, 600 grooves/mm). A more detailed description can be found in Osak *et al.* (1979). We used a Princeton Instruments CCD camera (256×1024) with a frame rate of up to 3 frames per second (16 in binning mode). Light modulation is conducted by a Displaytech FLC. This device functions as a half-wave plate. The observation was made for NOAA 680, 765, 779 in the following absorption lines: BaII 4554Å, FeI 6302Å in scanning mode. The telescope guiding system was used to move the selected region of the Sun relative to the spectrograph slit. The slit corresponds to 63×1 arcsec of the solar image.

Classical scheme 1 with alternative suppression of Zeeman's σ-, $\sigma+$ components. The scheme passes through a single σ component of Zeemans splitting in one modulation phase. Two frames with clockwise- and counterclockwise-polarized spectrum result from one modulation cycle. Subtraction of these two frames yields a V-Stokes profile.

Schemes with spatial modulation. *a) Magnetograph mode.* This scheme 2 is shown on Figure 1. If there is no magnetic field, the only cause of spectral line splitting in the system output is the polarization splitter (Figure 1b), Kobanov (2001). In state 1 FLC does not modify the polarization of σ- and $\sigma+$. If there is a longitudinal magnetic field toward the observer, the line components will split by $\Delta\lambda_H$ (Figure 1a). In the other modulation phase the FLC changes polarization of σ- and $\sigma+$ by 90. The components converge to the value of $\Delta\lambda_H$ (Figure 1c). This scheme utilizes a polarization splitter

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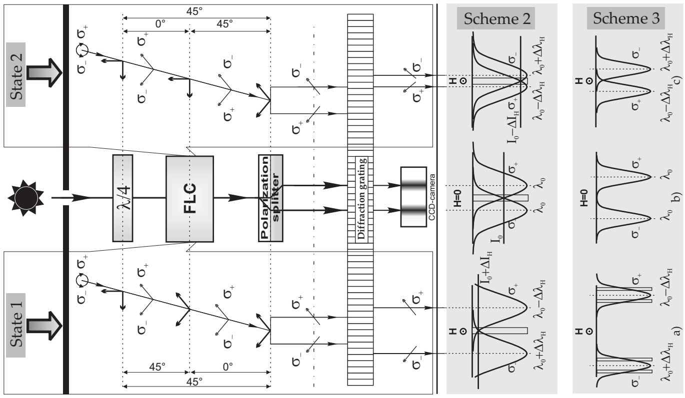

Figure 1. Optical schemes with spatial modulation to measure longitudinal magnetic field.

giving half-width line separation. To measure Zeeman's splitting value, an "electronic" slit is placed at the intersection point of the components (Figure 1, scheme 2). In different modulation phases the intensity level varies proportionally to the splitting. *b) Lambda-meter mode.* If we increase splitting in the previous scheme to completely separate the two components, the field strength and Doppler velocity can be directly determined by measuring the line centroid (λ-meter mode, Figure 1, scheme 3). *c) Scheme 4 without FLC modulator with spatial separation* is realized by removing the FLC from scheme 3. As before, the field strength and line of sight velocity can be determined by measuring the wavelength separation (λ-meter mode).

To estimate noise (threshold sensitivity) produced by each scheme, we do not apply flat field correction. To obtain the noise, we subtract two consecutive values of magnetic field for the same single space element. In the ideal case the difference (i.e. noise) will be zero. Below you can see the noise RMS averaged over all observed active regions: Scheme 3 shows the best result (17 Gs), Scheme 4 (28 Gs) and Scheme 2 (48 Gs) demonstrate moderate noise values, and Scheme 1 exhibits the maximum noise (83 Gs). Assuming magnetic field to be almost zero on the quiet Sun, the noise can be estimated directly from the final image: 10 Gs in Scheme 3; 24 Gs in 4; 34 Gs in 2; 58 Gs in 1.

With a slow CCD camera and slow scan speed, Scheme 3 shows the best result. If scanning speed is fast (faster than 1.5 arcsec/sec), the system has to provide exact synchronization between the image movement in the slit and the image acquisition process. Otherwise Scheme 4 appears to be preferable, since the magnetic field is resulted from a single frame (two frames are used in other schemes) and poor synchronization leads to less noise than with other schemes. The main disadvantage of Schemes 3, 4 is a limit on the number of working lines, due to blending. Scheme 1 needs high modulation frequencies and fast detectors, restricting the use of slow CCD cameras.

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