

Optimum frequency for the LOIS radar for investigation of CME events

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Abstract

To determine the optimum frequency for the LOIS radar for investigation of CME events we have to take into account the following points:

1. Location of the LOIS radar meaning aiming the radar beam. Possible refraction of radio waves in the ionosphere and the influence of the Es on radio wave propagation.
2. The frequency dependence of the background (cosmic) noise and quite Sun radiation.
3. Wave absorption in the solar atmosphere (in solar corona and chromosphere).
4. The nonlinear interaction of powerful radio waves with the ionosphere plasma; diffraction of radio waves in random media by their trans-ionosphere propagation.
5. The frequency dependence of CME cross section.
6. Dependence of frequency shift and broadening of scattered signals on sounding frequency.

1 Our understanding of the problems

1. Because you plan to place the LOIS radar in southern Sweden, its latitude will be of about 57° N (similar to the Sura facility). So the solar zenith angle in the south direction will vary from $\geq 35^\circ$ in the summer to $\geq 79^\circ$ in the winter (less than 11° over the horizon). In this case both refraction effects and sporadic *E* layers will play an important role for radio wave propagation, especially in the lower frequency range 10–30...50 MHz. It is important also to recall that these effects may be of irregular character thus destroying observations.

2. The cosmic noise temperature is about 500000° K at 10 MHz and depends on the frequency as f^α , where $\alpha \simeq -2.6$. So, $T = 500000 \times (f/10)^{-2.6}$. This temperature equals 6000° K (temperature for the solar photosphere under quiet Sun conditions) at $f \simeq 55$ MHz. At higher frequencies the Sun is a brighter object than the sky. But we have to keep in mind that the Sun radiation intensity increases strongly during burst and CME events. This may complicate the determination of geoeffective CME events. We cannot exclude the possibility that only events observed outside the solar disk can be detected.
3. $I = I_0 \times \exp(-\int \kappa dz)$, where κ is the absorption index. The $\kappa(f)$ dependence is mainly determined by the solar atmosphere profile and electron temperature. We can refer to the articles by *James*, in which he stated that the wave absorption in the frequency range 38–75 MHz increases approximately as f^2 . More detailed consideration of this point is in progress now.
4. No doubt that when we use powerful waves with an ERP ≥ 100 MW at $f \simeq 10$ –20 MHz, a generation of artificial plasma turbulence is usually observed due to, for instance, the self-focusing instability. These effects have been observed in our earlier measurements during overdense ionosphere heating, in experiments relating to oblique HF wave propagation, and in our SURAWIND experiments. Because the characteristic plasma field depends on f as $E_p \sim f$, higher frequencies are more preferable for sounding on this point. Scattering of radio waves due to the trans-ionosphere propagation is usually very strong at low frequencies (10–30 MHz) but decrease as f^2 with the increase of the sounding frequency.
5. We believe that the frequency dependence of the CME cross section have to be the subject for a future, more detailed investigations because we do not know exactly the features of CME turbulence. It seems that their scale length can be larger than the visible Sun disk. In the opposite case, they will be very difficult to recognise against the background of the solar radiation, especially for geoeffective CME events.
6. In the first approximation, the Doppler shift is determined by both the sounding frequency and the CME bulk velocity ($dF \propto fV$). The width of the scattered signal spectrum, δF , is determined by the turbulent motion inside a CME envelop. From *James's* experiments we can conclude that $dF \leq 15$ kHz and $\delta F \geq dF$ at 38 MHz. With an increase of the sounding frequency up to 200 MHz their magnitudes can be as large as 100 kHz and more.

As a rough approximate, it seems that the frequency range $f \geq 50$ MHz, for which the intensity of signals reflected from the inner corona is strongly suppressed, is the most preferable one for CME detection, and the frequency range $f \leq 30 \dots 50$ MHz is more preferable for the study of the outer solar corona.

Because the angular dimension of CME events showing reflected properties can reach of 5° and more, the transmitting antenna array has to be about 10λ . This gives antenna gain of about of 500-1000. Taking into account that at $f = 50$ MHz, the ERP has to be no higher than 250-500 MW (to exclude ionospheric nonlinear effects), the transmitter power have to be of about 0.5 MW here. It is expected that at higher frequencies nonlinear effects will be negligible at real sounding power. The latter can be easily tested using the 224 MHz ISR in Tromso.

Naturally, a more detailed consideration will take substantially longer time.