# INFERENCE OF MAGNETIC FIELDS FROM SOLAR FLARES

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**Abstract.** The magnetic field induction present in the flare region can be inferred from the observed spectrum peak by the gyro synchrotron theory. For homogeneous magnetic field the spectrum peak is well defined and may be used for the inference of the field induction whenever we know the other important source parameters. The magnetic induction is the strongest dependence of the peak frequency and has been widely inferred from these spectra peak in solar flare analysis. The non homogeneous magnetic field may modify the spectrum width and peak mainly due to changes in the optically thick spectral index. Thus, for non homogeneous magnetic field the inferred induction may be interpreted as an effective value when the observation is fit, for example, by the four parameter fit-function given by most of solar flare analysis in the literature. Simple formulas are given for the gyro-synchrotron spectra peak in the literature where the peak is derived for the opacity equal one. This simplification causes the peak to be uncertain mostly for the cases where the optically thin spectral index is low. Besides, these simple equations are not applicable for spectra peak occurring below the tenth harmonic number of the electron gyro-frequency which excludes most of the observed flares. We present a simple expression for the magnetic induction in a self-absorbed gyro-synchrotron emission to infer it from the spectrum peak frequency as given by the spectrum least square fit instead of opacity equal one. Our equation is valid for a large range of parameters generally accepted for solar flare conditions including peak frequency below the tenth harmonic of the gyro-frequency.

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## INTRODUCTION

### The Gyro-Synchrotron Spectrum from Solar Flares

The microwave emission from solar flares is tipically interpreted as gyrosynchrotron radiation from suprathermal electrons bottled in magnetic loops. The mildly relativistic energies radiate at the electron gyro-frequency and above as a continuum spectrum (see review in [1]). Possible harmonics of the gyro- frequency may be resolved when the magnetic field anisotropy is moderated [2]. Strong anisotropy would smoothen the optically thick part of the spectrum and lower the spectral index.

## SPECTRAL DETERMINATIONS

The radiation intensity at frequency $f$ from the solution of the transfer equation is shown in equation 1 for a homogeneous source. j and k are the emission and absorption coefficients, respectively, for the extraordinary (x) and ordinary (o) propagation modes. L is the source size in the line of sight direction called here by source depth and $\theta$ is the viewing angle of the field lines.

$$I_{x,o}(f,\theta) = \frac{j_{x,o}(f,\theta)}{k_{x,o}(f,\theta)}\left[1-e^{-k_{x,o}L}\right] erg\, s^{-1} sr^{-1} Hz^{-1} cm^{-2} \quad (1)$$

For the emission and absorption coefficient (j and k) determinations we used the complete formulae given by [3] with corrections of [4]. The total flux density spectra calculated are the crosses in all figures (see figures 1 to 5) and the thin line plotted above is the fit-function given by [2].

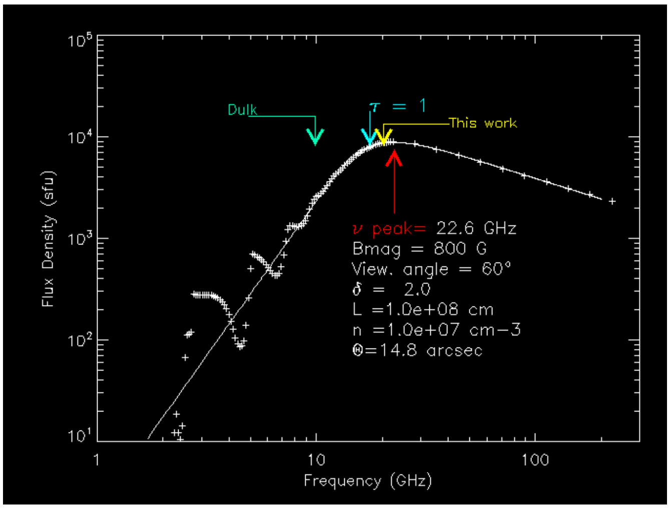


**FIGURE 1.** Spectrum from a cylindrical source with plasma and geometric parameters defined on the figure. The opacity equal one (blue arrow) defines a frequency that can differ from the peak frequency (red arrow) mostly when the electronic spectral index $\delta$ is low.

The fit was done in the range of parameters shown in table 1 in thousands of spectra and from these fits we found an empirical relationship between the spectrum peak frequency and the source parameters shown in equation 2.

$$f_{peak} = (n_6 L_9)^{0.12}[B_2(13.5 sin(\theta)e^{-\delta}+0.9)+0.5 sin(\theta)] \quad (2)$$

where any parameter represented as $X_i$ means X in units of $10^i$ (f.ex.:, B=500 G is $B_2$=5), n is the supra-thermal electronic number density in $cm^{-3}$, L is the source depth in cm, $\theta$ is the field lines viewing angle in degrees, B is the local magnetic induction in Gauss, $\delta$ is electronic power law spectral index and $f_{peak}$ is spectrum peak frequency in GHz. This equation can also be shown in the way it is more convenient for magnetic field inference, i.e.,

$$B_2 = \frac{1.1 f_{peak}(n_6 L_9)^{-0.12} - 0.6}{1+14.5e^{-\delta} sin(\theta)} \quad (3)$$

TABLE 1. Validity Range for the Parameters

| | L cm | n $cm^{-3}$ | $\theta$ deg | $\delta$ | B Gauss |
|---|---|---|---|---|---|
| Minimum | $5x10^7$ | $10^6$ | 20 | 2 | 100 |
| Maximum | $10^9$ | $10^8$ | 80 | 7 | 900 |

# OTHER EXAMPLES OF SPECTRUM

Similar to the spectrum presented in figure 1 here we show four other cases where the $f_{peak}$ inferred by equation 2 differs from the peak inferred from the equation given by [1], called here simply by Dulk's equation.

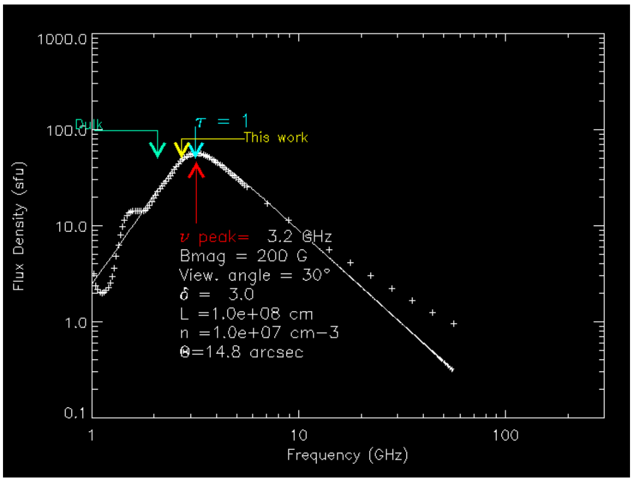


**FIGURE 2.** Similar figure 1 with diferent parameters shown on figure

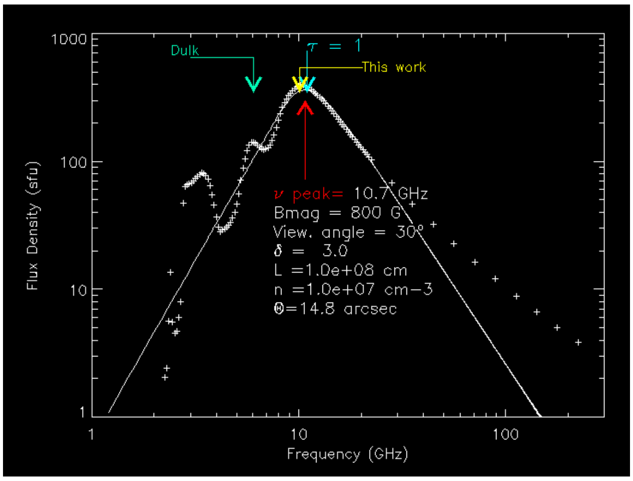


**FIGURE 3.** Similar figure 1 with diferent parameters shown on figure

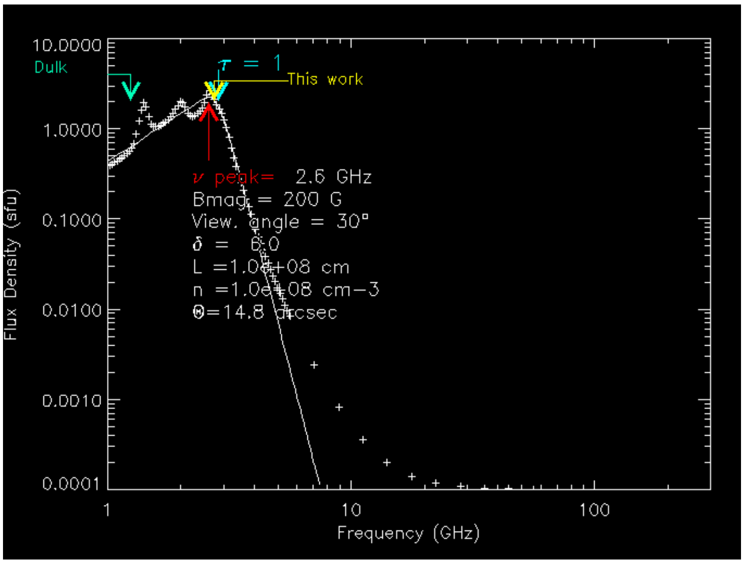


**FIGURE 4.** Similar figure 1 with diferent parameters shown on figure

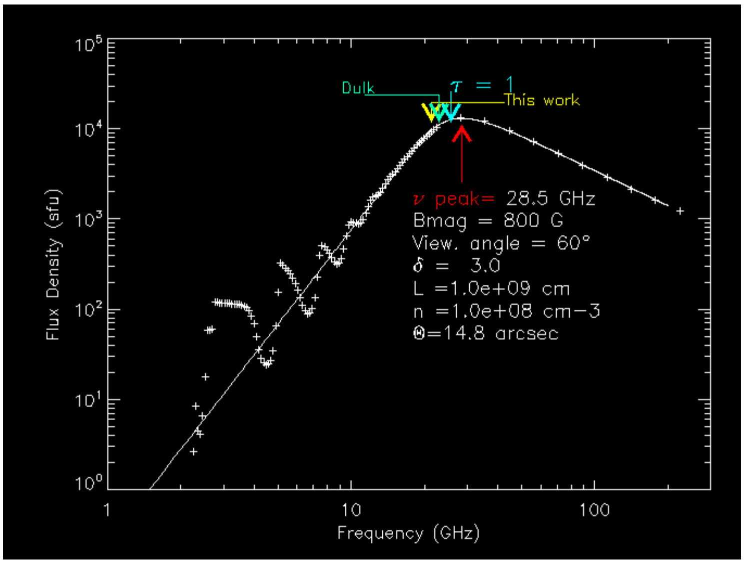


**FIGURE 5.** Similar figure 1 with diferent parameters shown on figure

## CONCLUSIONS

The spectrum of the homogeneous source fits very well the proposed fit-function even with the presence of the harmonic structures as can be seen in figures 1 to 5. In general, the observed spectrum has not many frequencies as plotted in our figures but the maximum is obtained and can be used for the B inference. The errors involved in $f_{peak}$ determinations were calculated using the Dulk's equation (see figure 6) and using our equation 2 (see figure 7). As shown by the error plots our equation decreases the errors in the $f_{peak}$ determination by a factor greater than three for almost all the parameters.

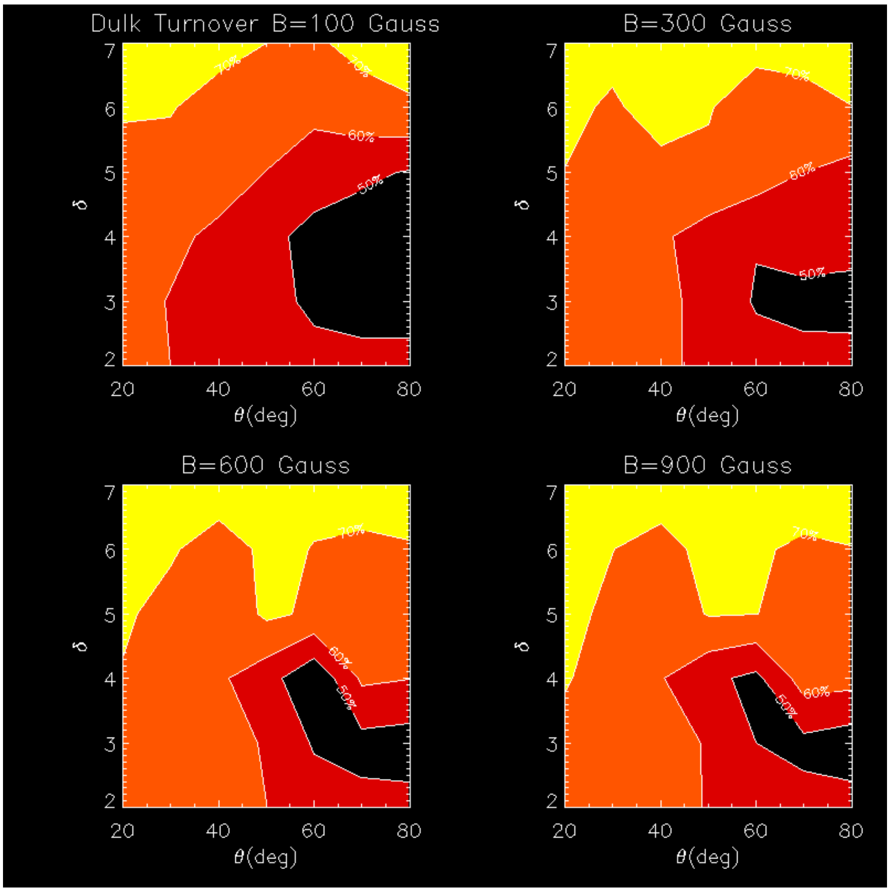


**FIGURE 6.** Relative errors in $f_{peak}$ calculated by Dulk's equation in relation to the peak determined by the least square fit. The relative error (percentage) is labeled in each contour (the inner regions are lower than the labeled number). On top of each figure is the magnetic field used to calculate the spectra. The $\theta$ (viewing angle) and $\delta$ (spectral index) are shown on the plot axis. The errors are the maximum error for all number density $n$ and source depth L in the range shown in table 1

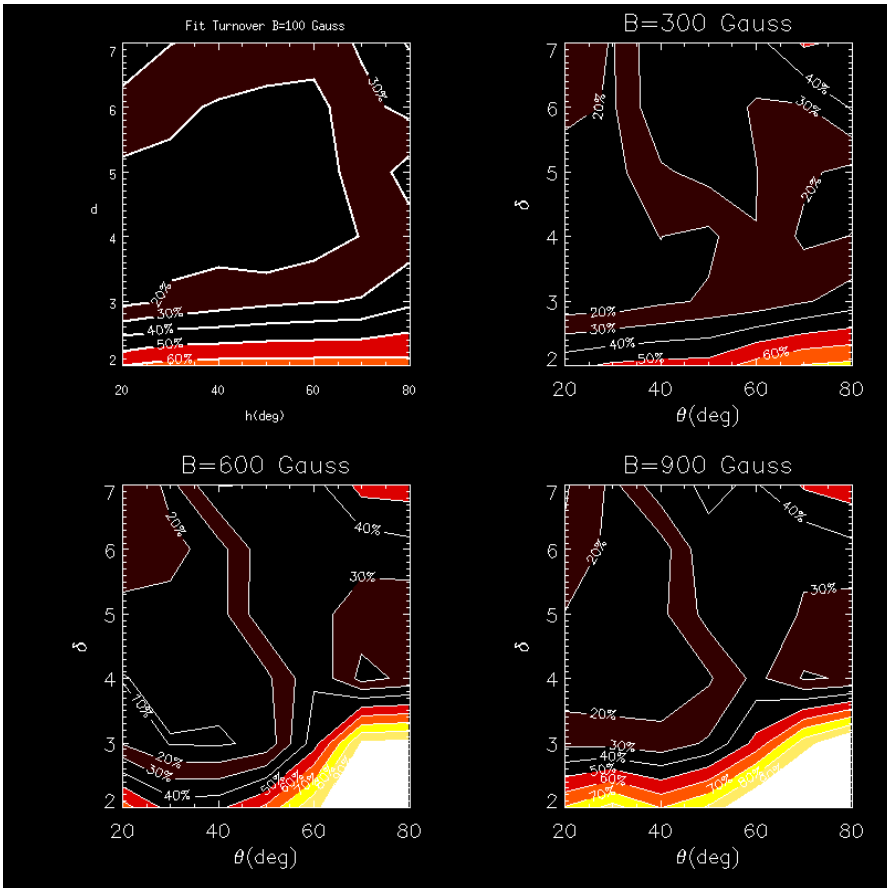


**FIGURE 7.** Relative errors in $f_{peak}$ calculated by the equation 2 in relation to the peak determined by the least square fit.

# ACKNOWLEDGMENTS

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