Towards the interpretation of the solar millisecond spikes

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Spike bursts in the decimetric range have been known for a long time as intense flashes of a few tens of milliseconds, and none of the few models has become established. The term of “spikes” is applied to small time scale (typically less than some tens of a second), narrow-band (typically between 2 and 15 MHz) single bursts occurring in groups of ten to thousands spread over several 100 MHz. Let’s present some results on spikes, which are of interest for further.

The magnitude of a flux of radio emission reaches the values $10^4 - 10^5$ s.f.u. Brightness temperature can reach 10^{16} K and even more. The longest duration is 200 ms at 230 MHz; the shortest times scale is 20 ms below 1 GHz. The time profile of spikes consists basically of a Gaussian rise and exponential decay time. Rising and decay processes are independent, which may be supported by the lack of any correlation between spike duration and decay rate or between peak flux and decay rate. The rise phase duration of spikes depends on the frequency (Güdel and Benz, 1990):

$$D_0(\nu) = 0.0325 \left(\frac{\nu}{661}\right)^{-1.49\pm0.17}, \ \mathrm{s}$$

The e-folding decay time also depends on the frequency:

$$\tau(\nu) = 0.0165 \left(\frac{\nu}{661}\right)^{-1.06\pm0.06}, \ \mathrm{s}$$

Drift rates in frequency and in time show a wide scatter over positive and negative values, but negative drift dominates, and the peak of the broad distribution is between -100 – 500 MHz/s at 362 MHz and between -1000 – 4000 MHz/s at 770 MHz (Güdel and Benz, 1990).

Within the framework of the plasma hypothesis of spike generation, which accepts by many authors, the duration of spikes is determined by propagation time of a beam of fast electrons with beam dimension l and the velocity V of the fixed layer of the solar atmosphere. Thus, to explain the value of D_0 , we have to assume a defined value of other unknown value of l.

That is, apparently, some weakness of the plasma hypothesis. It should be noted also that the type III bursts, where the plasma mechanism of generation of radio waves is generally accepted, decay time are longer than the decay times of spikes by factors of about $12-14$. Therefore we consider here the gyrosynchrotron instability of mildly relativistic electrons as the mechanism of generation of radio spikes. Such approach was applied in a number of papers (see e.g. Mosunov and Charikov, 1995; Stupishin and Charikov, 1998). In this mechanism there are no problems with high brightness temperature, but as well as in the plasma mechanism there are difficulties with explanation of duration of spikes. Stupishin and Charikov (1998) suggested that the duration of spikes is connected with the time scale of a nonlinear relaxation of accelerated electrons on Langmuir waves. Thereby, they keep to the plasma hypothesis.

In the present contribution we shall try to explain their duration based on the independent data of burst generation region and on simple physical conceptions, without assumption about decisive role of Langmuir turbulence in spikes. From spectral features of the flare radio emission of a different power Yasnov and Khokhlov (1998) have shown that generation of fast electrons occurs in thin filaments, which thickness less then 2×10^6 cm, and with the length between 10^8 and 10^9 cm. In these filaments bulk plasma is accelerated practically up to subrelativistic energies. These circumstances can explain the duration of spikes. Because there is no background plasma in the generation region of electrons the gyrosynchrotron instability is very effective here, giving emission with the high brightness temperature. As soon as the electrons escape from the acceleration region, the background plasma completely suppresses gyrosynchrotron instability and the spike radiation is ceased. The spike duration is explained simply by time of electron escaping from the generation region. Let's carry out appropriate calculations supporting this idea.

As an example we consider a rather general form of a distribution function of fast electrons $u(\gamma)$,at which gives a possibility for negative reabsorption. We suppose also that this distribution is isotropic:

$$u(\gamma) = C\, u_1(\gamma)(1 - exp(-\frac{\gamma - \gamma_c}{\gamma_0})), \qquad (1)$$

here γ is the Lorentz's factor, C is the normalization constant, γ_c, γ_0 are parameters describing the distribution function for the small values of electron energy , $u_1(\gamma)$ is the power-law function with an index δ. Note that for anisotropy of a type of $sin^n\theta$ (θ is pitch-angle, $n = 10 - 20$), which can be expected in a magnetic trap, the results are practically the same. A gyroresonance radiation (the power of emission as a function of frequency) were calculated using the formulas by Ramaty (1969) with the corrections on the background plasma. Stupishin and Charikov (1998) have shown that negative reabsorption is effective for large angles of observation $\Psi > 70°$. Therewith it was shown that the most high-power radiation arises in the region of the 2nd harmonic of a gyrofrequency. The calculations for $\Psi = 80°$ and for frequency range close to 2-nd harmonic of a gyrofrequency are indicated on Figures.

The preliminary calculations suggested that the negative reabsorption for the distribution function in Eq.1 becomes appreciable for $\gamma_c = 1.018$. The parameters of the generation region of electrons are indicated in Figures. In Fig.1 the spectrum of a radiation is presented for the background plasma density $N = 0$, in Fig.2 for $N = 3.5 \times 10^7$ cm^{-3}. This value is close to the critical one. For $N > 3.5 \times 10^7$ cm^{-3} the negative reabsorption is absent. It is clear that the emission power in the maximum of the spectrum drops up to 11 orders. It also determines full suppression of a spike radiation when the electrons escape the generation region.

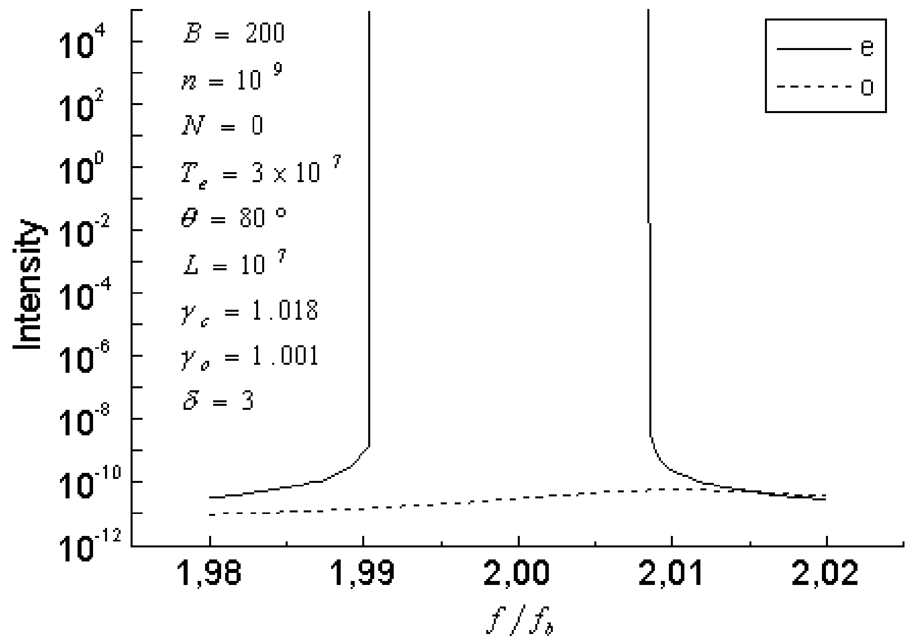

Figure 1: Spectrum of a gyrosynchrotron radiation close 2nd harmonics of a gyrofrequency (f_b) for the ordinary (o) and extraordinary (e) waves for the distribution function of electrons (Eq.1). Background plasma density $N = 0$

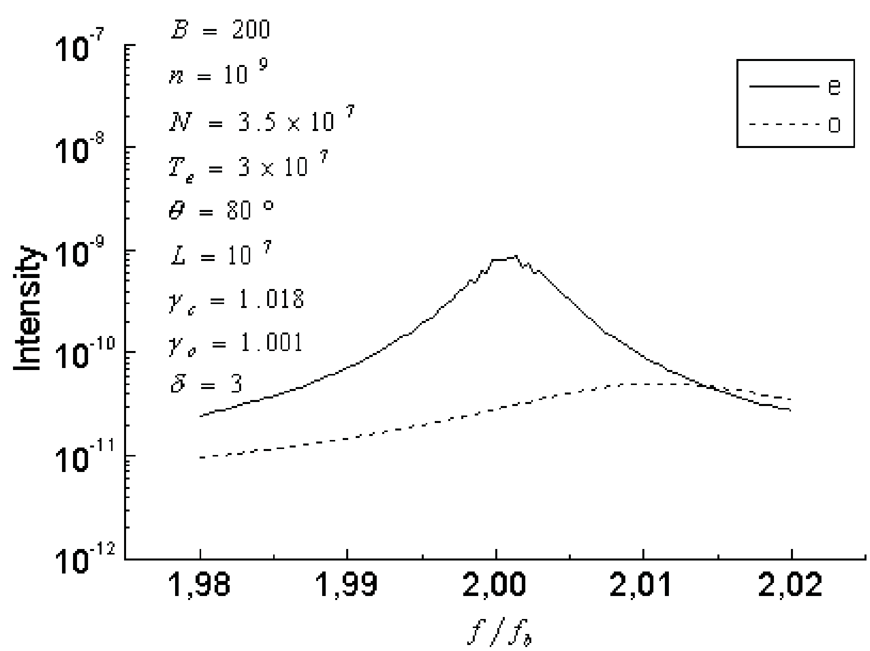

Figure 2: The same for the background plasma density $N = 3.5 \times 10^7$ cm^{-3}

The average velocity of electrons which are responsible for negative reabsorption is determined by value γ_c, that is $V \approx 4 \times 10^9$ cm/s. If duration of a spike is 100 ms, then the length of the generation region has value 4×10^8 cm, that well corresponds to an independent evaluation mentioned above ($10^8 - 10^9$ cm). In this model it is possible to understand, why τ does not correlate with some other characteristics of spikes. The intensity of emission depends on the value of a positive derivative in the distribution function, on an amount of fast electrons, but τ does not depend on these parameters and it is determined only by velocity of particles which have energy of γ_c.

The frequency drift of spikes in this model is connected with a gradient of a magnetic field in the generation region of radio emission and it can be estimated as:

$$\dot{\nu} = \frac{\nu}{2H} V$$

Where ν is the frequency of a radiation, H is the characteristic scale of a magnetic field along of the filament, V is the velocity of the electrons. Supposing $\dot{\nu} = -500$ MHz/s for $\nu = 362$ MHz and $\dot{\nu} = -4000$ MHz/s for $\nu = 770$ MHz, we obtain that H is within the interval of $1.5 \times 10^9 - 0.4 \times 10^9$ cm. It corresponds well to the value obtained by Yasnov (1993) from the analysis of dynamic spectra of microwave flares (0.9×10^9 cm).

References

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