THE MICROWAVE SPECTRUM OF SOLAR MILLISECOND SPIKES

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Abstract. The microwave radiation from solar flares sometimes shows short and intensive spikes which are superimposed on the burst continuum. New observations at 3.47 GHz with high temporal and spectral resolution have revealed lifetimes of less than 10 ms and bandwidths between 0.5 and 200 MHz. Simultaneous measurements at two further frequencies showed no coincident spikes at the second and third harmonic. The spikes can be explained by the theory of electron cyclotron masering if the observed bandwidths are determined by magnetic field inhomogeneities or if the rise times are independent of the source diameters. The latter would imply source sizes between 50 and 100 km.

1. Introduction

Millisecond microwave spikes are intensive and very short fine structures which are occasionally superimposed on the microwave continuum of solar flares (Figure 1). They have mainly been observed at the lower end of the microwave spectrum up to ~ 6 GHz (Dröge, 1977; Slottje, 1978 and 1980; Zhao, 1983; Stähli and Magun, 1985). The duration of most of the spikes was reported to be shorter than 20 ms and the deduced brightness temperatures of the spikes were in the range between 10^{13} and 10^{15} K. In order to resolve and study the spectral and temporal fine structures of millisecond spikes a digital spectrometer with a time resolution of 5 ms was constructed (Stähli, 1983). Its center frequency was set at 3.47 GHz and its total bandwidth of 200 MHz was continuously covered by 30 channels with bandwidths varying between 0.5 MHz and 30 MHz. The frequency range was extended by two fixed frequency polarimeters at 3.1 and 5.205 GHz. For the simultaneous observation at the second and third harmonic of the gyrofrequency the latter was chosen at 3/2 of the spectrometer center frequency.

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I 3.2. F=3.2 GHZ. BW=100.0 MHZ. T=0.100 SEC
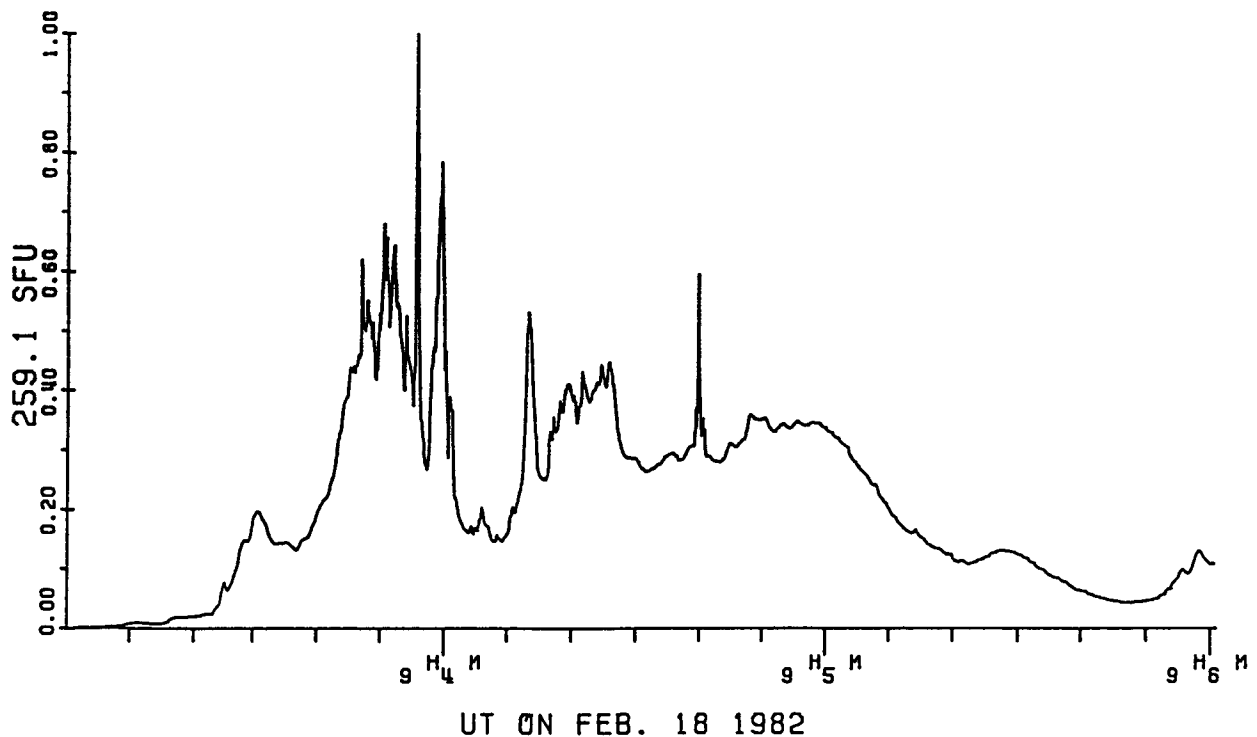
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Fig. 1. Typical time profile of a solar radio burst at 3.2 GHz with superimposed millisecond spikes. The integration time is 100 ms.

In this paper new spectral observations of microwave spikes which were obtained with our fast spectrometer are presented and the proposed gyrosynchrotron maser emission tested. The concept of harmonic radiation by electron-cyclotron masers (Holman et al., 1980; Melrose and Dulk, 1982; Sharma et al., 1982) provides a plausible explanation for the observed characteristics of the spikes.

2. The spectrum of millisecond spikes

2.1. Observations

Between August 1982 and May 1983, 107 events have been observed, of which 14 exhibited microwave spikes. The fine structures appeared either as single spikes or in groups (Figure 2). The duration, rise and fall times of most of the spikes were between 5 and 10 ms. These values correspond to the instrumental resolution of 5 ms and we therefore believe that the temporal structures of these spikes could not be resolved.
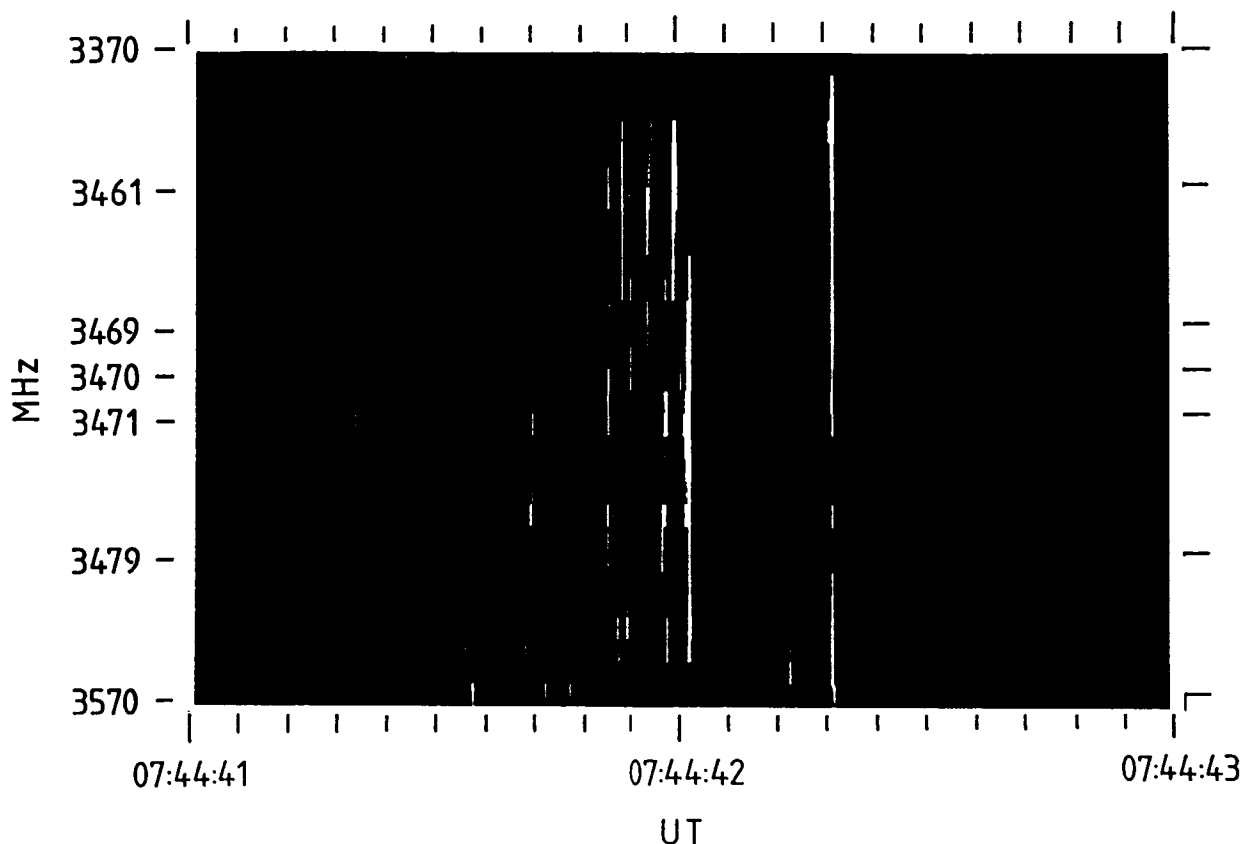
Fig. 2. Dynamic spectrum of millisecond spikes with subtracted continuum. The
event of December 25, 1982 was observed with an integration time of 5
ms and a spectral resolution between 0.5 and 30 MHz.

The brightness temperatures of single spikes were derived from the rise
time and the intensity under the assumption that the growing wave within the
source propagates with the speed of light. Temperatures usually exceeded 10^{10}
K but were always below 10^{12} K. The bandwidth of the spikes varied from less
than 0.5 MHz to more than 200 MHz. However, the bandwidth must be smaller than
approximately 300 MHz because no simultaneous spikes have been observed with
the spectrometer centered at 3.47 GHz and the nearest single frequency
polarimeter at 3.1 GHz. Additionally, no spikes were found to occur
simultaneously at the second and third harmonic of the local gyrofrequency.

2.2. Discussion

The spectral data has been used to test the cyclotron maser theory
(Melrose and Dulk, 1982). It predicts spike emission mainly slightly above the
second or third harmonic of the local gyrofrequency with brightness
temperatures up to 10^{15} K and very short rise times. The work of Melrose and

Dulk (1982) was used to derive relationships between observed spike parameters as flux density, brightness temperature and bandwidth, which are suitable for testing the proposed emission mechanism. Because of the many free parameters describing the loss cone and the ambient plasma only approximate formulae were used.

The relationship between brightness temperature T_b and relative bandwidth $\Delta\omega/\omega$ of the growing wave in the source was derived from (16) of Melrose and Dulk (1982):

$$T_b \approx m\; v_\bullet^2 \; (\frac{2\pi c}{\omega})^2 \frac{1}{L r_\bullet}$$

where $v_\bullet$: mean velocity of the m : electron mass
          radiating electrons
        c : velocity of light ω : frequency
        $r_\bullet$: classical electron radius L : trap length

With $\dfrac{\Delta\omega}{\omega} \approx v_\bullet^2/c^2$, $\dfrac{\omega}{2\pi} \approx 3$ GHz and $L \approx 10^{10}$ cm this reduces to

$$T_b \; [K] \approx 10^{15} \; \frac{\Delta\omega}{\omega} \tag{1}$$

which is a linear relationship between the brightness temperature and the relative bandwidth of the spikes under the assumption of a homogeneous source. The above expression is only valid if the saturation is due to the fundamental radiation which usually grows fastest. A recent and more detailed analysis of the growth rates (Winglee, 1985) has shown that for $v/c > 0.5$ the second harmonic dominates. This would lead to even higher brightness temperatures than given above.

The scatterplot (Figure 3a) shows the derived brightness temperatures and the relative bandwidths of the observed spikes, which were resolved in time and frequency. Relationship (1) is represented by a dashed line. It is obvious that the two parameters are uncorrelated in contrast to the prediction. The deduced temperatures are too low or the relative bandwidths are too large for which several explanations are possible: 1) Larger observed bandwidths than predicted could be due to magnetic field inhomogeneities within the source whose influence is not included in the theory. 2) The low brightness temperatures could be the result of overestimated source sizes. In this case source diameters and observed rise times must be uncorrelated which is for instance true if the latter is determined by the dynamics of the electron distribution.

T_b [10^{10}K]

10—

5—

0—

10   20   30

$\Delta\omega/\omega$ [‰]

S [SFU]

d=200km

d=100km

d=70km

d=50km

200—

150—

100—

50—

0—

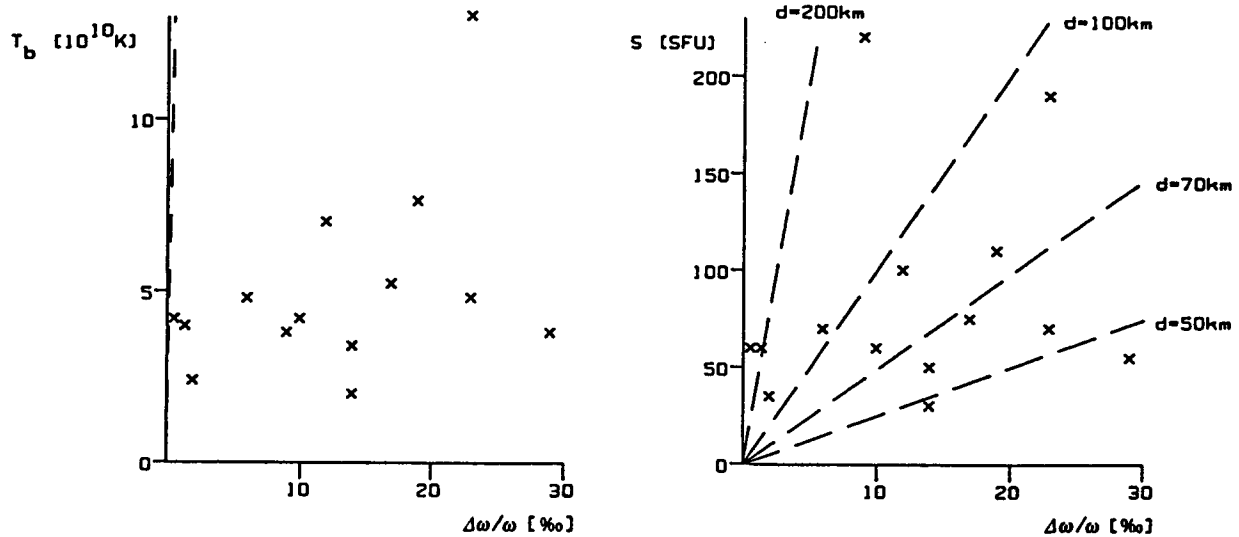10   20   30

$\Delta\omega/\omega$ [‰]

Fig. 3. Scatterplots of derived brightness temperature (a) and observed flux density (b) versus the relative bandwidth of observed spikes. The dashed lines represent the theoretical approximations. d is the source diameter.

In order to avoid the assumption of correlated source sizes and rise times the observed flux density of the same sample of spikes was plotted against the relative bandwidth (Figure 3b). The theoretical relationship for different source diameters was derived from (1) by using the Rayleigh-Jeans approximation:

$$S \ [SFU] \ \approx \ d^2_{[km]} \cdot \frac{\Delta\omega}{\omega} \qquad\qquad (2)$$

S : flux density in SFU   d : source diameter in km
$\frac{\Delta\omega}{\omega}$: relative bandwidth

If we assume that the bandwidth is not determined by inhomogeneities and the rise time does not depend on the source geometry, diameters between 50 and 100 km could explain most of the spikes.

These first observations of the spectral fine structures of millisecond spikes establish several new features. However, they also indicate that for a detailed analysis, better observations with higher temporal and spectral resolution including circular polarization are essential. For further investigation of the important electron spectrum it is also necessary to correlate microwave data with spike observations in other spectral ranges (hard X-ray, decimetric radio waves).

Acknowledgements

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