ON SPLIT-BAND STRUCTURE IN TYPE II RADIO BURSTS FROM THE SUN

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Abstract (*Astrophys. Letters*). The measured amount of band-splitting, Δf, in the spectra of nine harmonic type II bursts is illustrated in Figure 1. Here, as in previous, smaller samples (Roberts, 1959; Maxwell and Thompson, 1962; Weiss, 1965) Δf is found to increase with frequency, f.

Three kinds of interpretation of band-splitting have been offered:

(1) The splitting is due to a magnetic field; this interpretation predicts frequency-splitting in the range $f_H^2/2f_p \lesssim \Delta f \lesssim f_H$, where f_H and f_p are the electron gyro and

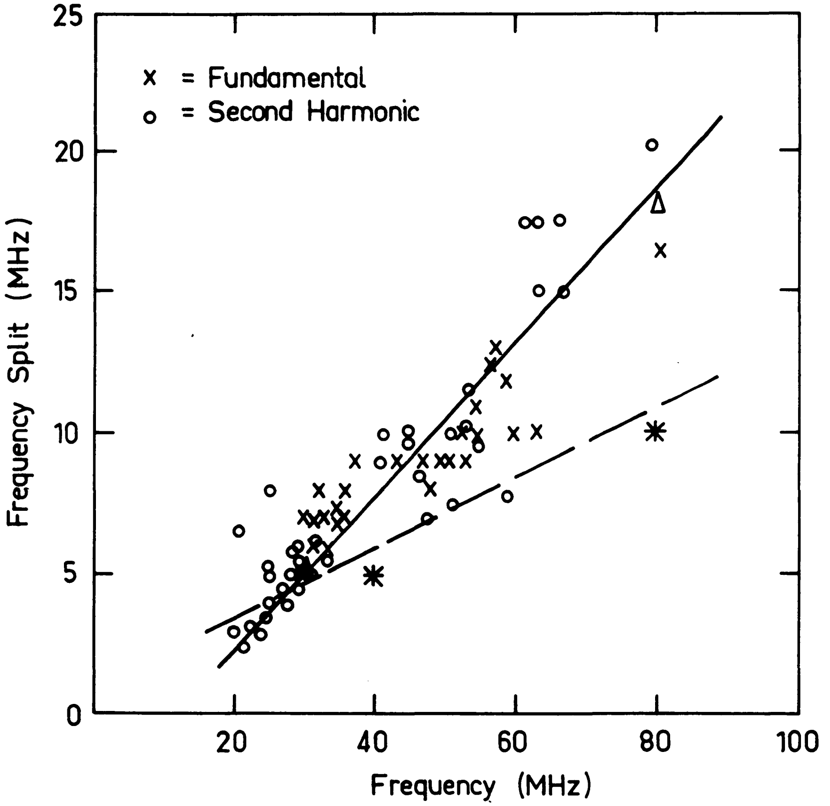

Fig. 1. The frequency separation of the two components in split-band type II bursts as a function of the mean fundamental frequency. Measured second-harmonic frequencies have been halved. The full line is a linear approximation to the present results, the broken line a similar approximation given by Weiss (1965). The points marked are mean values quoted by Maxwell and Thompson (1962), those marked △ are mean values quoted by Roberts (1959).

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plasma frequencies respectively and $f_H^2/f_p^2 \ll 1$. Weiss (1965) has shown that the derived magnetic fields would make the Alfvén velocity in the path of the type II disturbance larger than the speed of the disturbance. The latter could then not be a magneto-hydrodynamic shock, as is generally assumed.

(2) The splitting is due to a Doppler shift because the radiating electrons drift in opposite directions within the rising and falling branches of the shock wave. Wild and Smerd (1972) have suggested that there could be no such Doppler shift in the fundamental radiation since the latter results from the scattering of plasma waves on 'stationary' ions.

(3) The two components of a split band correspond to two maxima in the spectrum of the plasma radiation from a type II shock front. In McLean's (1967) model they originate near the axis and around the skirt of a coronal streamer because in both regions the shock front is nearly parallel to the plasma levels (though at different plasma frequencies).

Here we add another interpretation which, if correct, allows the determination of the shock strength of the type II disturbance and of the magnetic field along the path of the disturbance. According to the present hypothesis the frequency (f_l) of the lower-frequency component of a split band is identified with the plasma frequency (f_{p1}) just ahead of the shock front, while the frequency (f_u) of the upper-frequency component is identified with the plasma frequency (f_{p2}) just behind the shock; thus: $f_l = f_{p1}$, $f_u = f_{p2}$ and $\Delta f = f_u - f_l$.

This assumes (a) that radiating electrons exist at the front and the back of the shock front and (b) that, since the shock front is thin, the two components of a split band are emitted essentially from a common source. The latter assumption is supported by the occurrence at similar times of similar spectral features in the two components, a characteristic that may be hard to explain by McLean's (1967) theory. The assumption (a) may be supported by the occasional observation of 'herringbone' structure, which we takes as evidence for the forward ejection of electrons from the front, and backward ejection from the back, of a type II shock. The frequency interval that constitutes the 'backbone' can be interpreted in the same way as proposed here for band-splitting. This interpretation is made more plausible by the observation that in some cases the 'backbone' is itself split. It seems possible that the electrons exciting the plasma waves may be confined near the front and the back of a type II shock (the split-band situation) or ejected forwards and backwards (the herringbone situation), or both. The ejection of the electrons may depend on their having access to open magnetic-field lines.

With the present interpretation the band-splitting can be related to the Mach number through the Rankine-Hugoniot 'jump' condition

$$N_2/N_1 = f_{p2}^2/f_{p1}^2 = 4M^2/(3+M^2),$$

which connects the post-shock, N_2, and pre-shock, N_1, electron densities. Here the magnetic Mach number $M = v/v_A$, where v is the shock speed and $v_A = 7 \times 10^3 f_H/f_p$ is the Alfvén velocity. The measured frequency-splitting then determines the strength of a type II shock as

$$M = \frac{\sqrt{3}(f_u/f_l)}{\sqrt{4-(f_u/f_l)^2}}.$$

The derived shock strengths corresponding to the frequency-splitting of Figure 1 are shown in Figure 2; the frequency range of Figure 1 has been converted to a height range using Newkirk's (1961) streamer model. We note that the derived shock

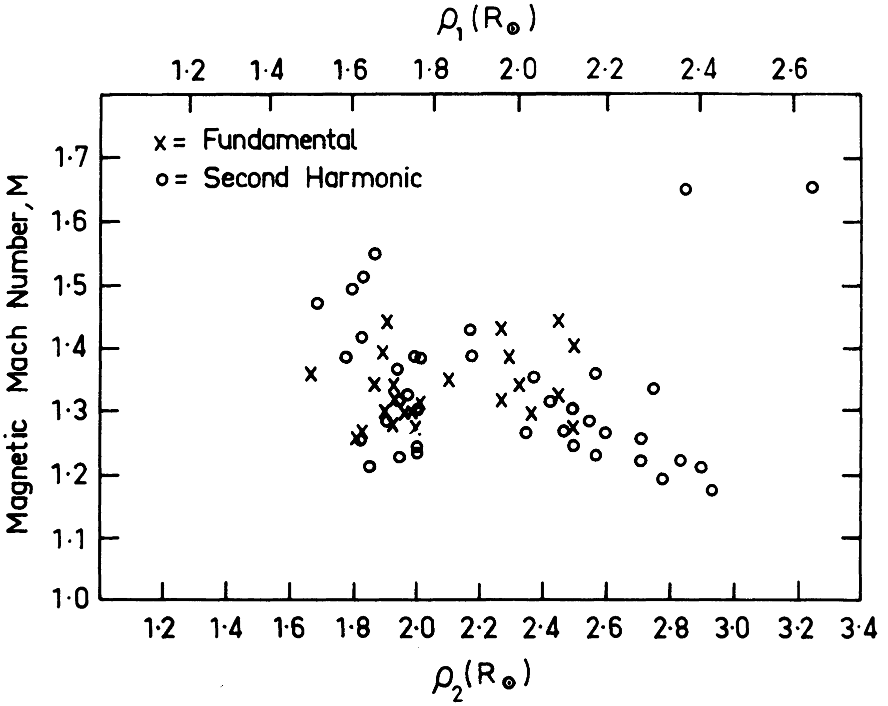

Fig. 2. The magnetic Mach number $M = v/v_A$, a measure of the shock strength of type II disturbances, as derived from the frequency-splitting of Figure 1. In converting from a frequency, f, scale to one of distance, ϱ, from the Sun's centre it has been assumed that f is the local plasma frequency along the axis of a Newkirk streamer (ϱ_1), or along a streamer with twice those densities (ϱ_2).

strengths ($1.2 \lesssim M \lesssim 1.7$) are compatible with a laminar shock structure, but are below hose ($2.0 \lesssim M \lesssim 2.9$) required in Smith's (1971, 1972) theory of turbulent type II shocks.

It is clear from the above that a knowledge of the shock strength, M, and the shock speed, v, yields the magnetic-field strength in the plasma ahead of the shock front as

$$H = 5.1 \times 10^{-5}\, v f_l / M \quad \text{G},$$

where v is in kilometres per second and f_l in megahertz. As in previous type II analyses, we derive the shock speed from the measured frequency-drift rates, assuming a radial path and a coronal density model. The magnetic fields derived in this way,

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again using Newkirk's streamer model, are shown in Figure 3. The points are widely scattered in the range 0.4 to 4.0 G. The main uncertainty is probably due to uncertainty in v resulting from a lack of knowledge of the actual path of the disturbance and of the densities along this path.

In a few cases the positions of both components of a split band have been observed

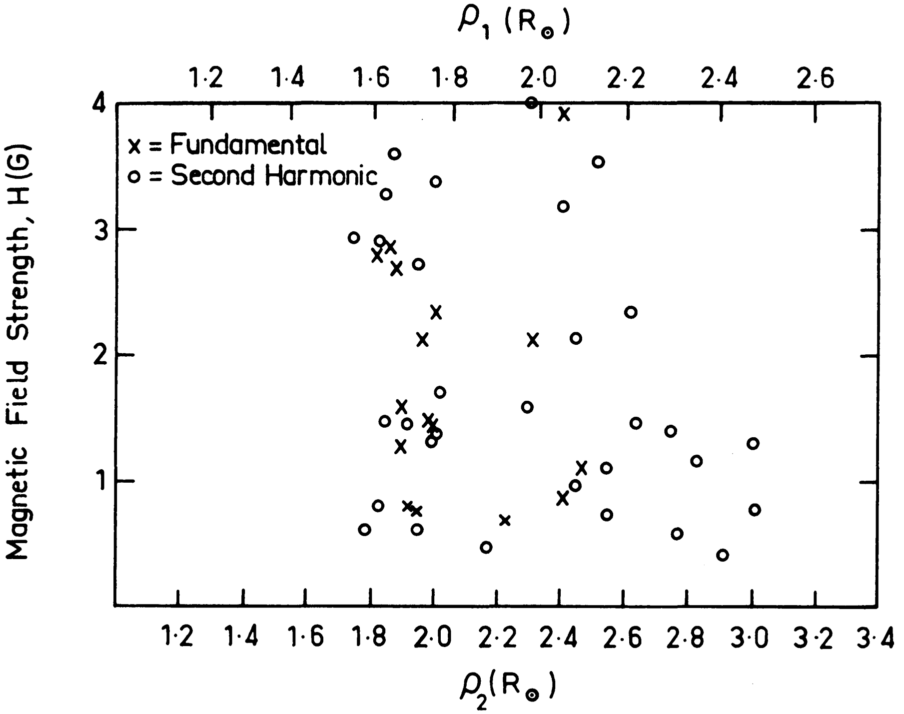

Fig. 3. The magnetic-field strength, H, as a function of distance ϱ from the Sun's centre derived from the frequency-splitting shown in Figure 1 and the radial velocities of the type II disturbances deduced from the spectral drift rates and the same two coronal streamer models (ϱ_1, ϱ_2) as in Figure 2.

with the Culgoora radioheliograph: the sources are separated by 1′ to 4′. This has been taken in support of McLean's (1967) theory (see (3) above). Some of the source separation, say ~1′, may simply reflect the distance covered by the type II disturbance during the interval (~1 min) between the appearance of the lower-frequency and the upper-frequency components at the heliograph frequency. However, the present theory suggests two further causes of apparent source separation.

(1) In the fundamental band the f_l-component is emitted in the undisturbed corona. Its apparent position is expected to be well beyond the true projected position, largely because of the strong, refractive outward-beaming near the plasma level (e.g. Riddle, 1972). Meanwhile the f_u-component has only to cross the shock front before emerging from the strongly refracting region; its position should be nearer the true position.

(2) While fundamental radiation can escape only outwards, harmonic radiation

can reach the observer by 'direct' or 'reflected' rays. This effect could be responsible for well-separated $2f_l$ and $2f_u$ sources if, as suggested by the comparison between split-band and herringbone structure, the radiating electrons ahead of the shock front are beamed forwards, those behind the shock front backwards.

However, the present sample of observed split-band positions is too small to decide between different split-band theories.

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DISCUSSION

Smith: One of the reasons for accepting Weiss's idea that herringbone is due to a shock crossing a magnetic field was that there was often no frequency drift when herringbone was observed. What do you think about this now?

Smerd: Weiss had a very small data sample.

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