SLOW DRIFT SOLAR RADIO BURSTS: HARMONIC FREQUENCY RATIOS, SOLAR LONGITUDE DEPENDENCE, AND FREQUENCY DRIFT RATES

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Summary

Frequency ratios of second harmonic to fundamental bands are determined for 19 slow drift bursts. The ratios measured at the high frequency edges of the bands yield a mean value of 2·00, whereas the mean value of the low frequency edge ratios is significantly lower than 2.

No definite solar longitude dependence is observed in either the number of bursts occurring or in the second harmonic to fundamental frequency ratios; further, fundamental bands do not drop out for sources far from the centre of the disk.

Frequency drift rates are found to bear no definite relationship to the geomagnetic effectiveness of the bursts.

I. INTRODUCTION

One of the features of greatest interest appearing on solar radio noise records is the " slow drift burst ". This event, observed with dynamic spectrum equipment, is an extremely intense outburst which drifts from higher to lower frequencies over a typical frequency range of about 200 down to 50 Mc/s in about 5 to 15 minutes. Slow drift bursts are comparatively rare events associated with certain solar flares, and are typically observed to have fundamental and second harmonic bands.

Wild, Murray, and Rowe (1954) proposed a model in which slow drift bursts are produced by plasma oscillations in the solar corona, with fundamental bands centred around the local plasma frequency. These authors predicted that the frequency ratio of second harmonic to fundamental, measured at peak intensity points, should be slightly less than 2. This prediction was based on their picture of cut-off of the low frequency part of the fundamental band due to complete absorption below the plasma frequency. Observations by these authors and later by Roberts (1959) confirmed this suggestion. The prediction was also made that the frequency ratio should decrease with increasing source distance from the centre of the Sun, and that the fundamental band should drop out altogether for distances greater than about a half a solar radius. However, these latter predictions of centre-to-limb variations have not been borne out by the later observations of Roberts (1959) or of Maxwell, Thompson, and Garmire (1959). No definite variation with solar longitude in either frequency ratio or in number of bursts occurring was observed by these authors.

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The present study extends these observations, using both the early and the recent data obtained at the Harvard Radio Astronomy Station, Ft. Davis, Texas. The first part of the paper will be concerned with harmonic frequency ratios and with solar longitude dependence; the second part will deal with frequency drift rates of the bursts and their relationship to geomagnetic activity.

II. Second Harmonic to Fundamental Frequency Ratios; Solar Longitude Dependence

In Figure 1 is shown a very idealized drawing of a slow drift burst with fundamental and second harmonic bands. Time increases from left to right in the horizontal direction; frequency increases from top to bottom in the vertical. The points are drawn on to show how harmonic to fundamental frequency ratios (f_2/f_1) are obtained on both the low frequency and the high frequency edges of the bands. According to the model of Wild, Murray, and Rowe (1954), in which

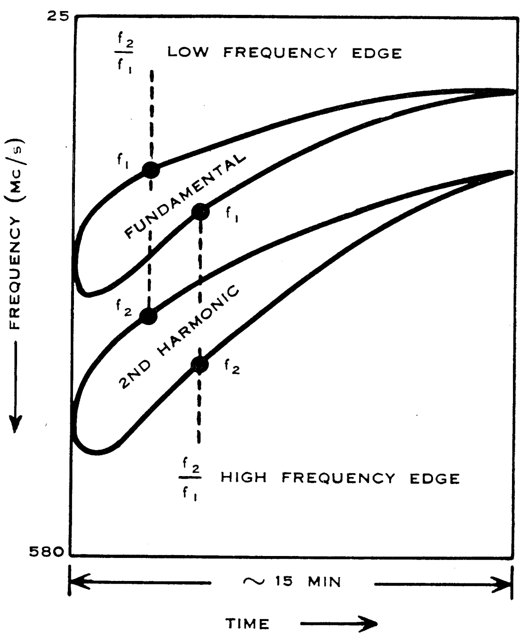

Fig. 1.—Idealized picture of harmonics in a slow drift burst.

loss of the low frequency part of the fundamental occurs, the low frequency edge values of f_1 should be raised in frequency, while f_1 at the high frequency edge should not be affected. We would thus expect low frequency edge values of f_2/f_1 to be less than 2, while those for the high frequency edges should approximate 2.

To test this prediction, f_2/f_1 values were measured from the Ft. Davis films. From October 1956 to December 1958 the frequency range covered by this swept frequency equipment was 580 down to 100 Mc/s; since the beginning of 1959 the low frequency end of the observing range has been extended down to 25 Mc/s.

Frequency ratios were obtained for both low frequency and high frequency edges, and several measures were made whenever possible at different times on a single burst. Nineteen bursts entered this sample. For the 1959 data, with the low frequency extension, about 75% of the bursts showed second harmonic and fundamental bands, although frequency ratios were measured on only the more clear-cut examples. No case of a third harmonic was observed.

The results of the study confirm our prediction that low frequency edge ratios should be reduced in value because of absorption, while the high frequency ones should remain unchanged. Figure 2 (*b*) shows the low frequency edge ratios; here the mean value of f_2/f_1 is $1 \cdot 90 \pm 0 \cdot 06$ (p.e.). Figure 2 (*a*), the histogram for the high frequency edge ratios, yields the mean value $2 \cdot 00 \pm 0 \cdot 03$ (p.e.). The probability that this large a difference could occur by chance is about 10^{-4}. This value is obtained using the *t*-test for the difference between two sample means (cf. Crow, Davis, and Maxfield 1955).

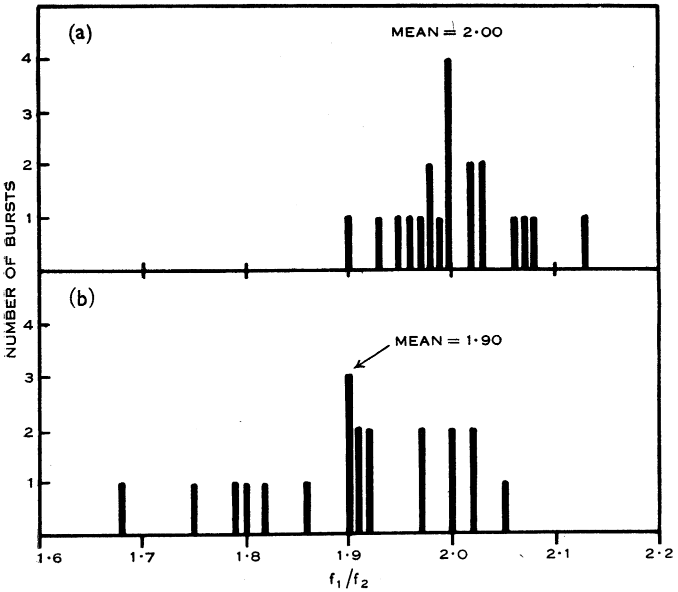

Fig. 2.—Harmonic frequency ratios: (*a*) at high frequency edges and (*b*) at low frequency edges.

In evaluating this probability figure, one must take into account the possibility of a systematic error which could arise from varying receiver sensitivity with frequency. However, care was taken to avoid measurements near insensitive bands, and it is felt that the results have not been basically affected. It is reassuring in this regard that when f_2/f_1 values are studied as a function of frequency of measurement, no definite variation in ratios occurs.

As the next step in the investigation, f_2/f_1 values are plotted in Figure 3 against solar longitude. Positions of the bursts are inferred from positions of time-associated flares. In agreement with the results of the authors previously mentioned, the ratios show no definite decrease in value toward the limb and, certainly, fundamental bands do not drop out for large central meridian distances.

In Figure 4, the frequency of occurrence of the bursts themselves, rather than f_2/f_1 values, is plotted against solar longitude. The upper histogram is for all bursts whose positions could be determined from time association with a solar flare ; the lower graph is for the flare-matched bursts that showed a definite fundamental and second harmonic. Although there is a slight tendency for drop-off away from central longitudes, the effect is no greater for bursts with fundamental and harmonic than for the total sample. Thus again, in this analysis, fundamental bands are not lost toward the limb.

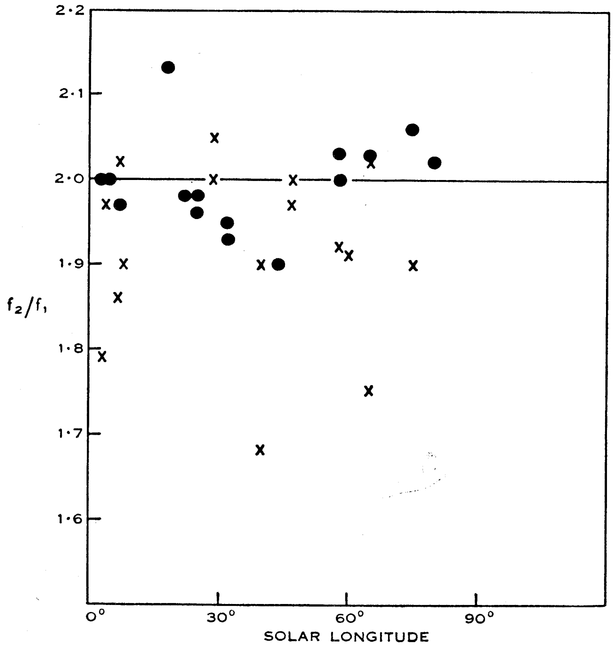

Fig. 3.—Harmonic frequency ratios as a function of solar longitude. ● High frequency edge, × low frequency edge.

In summary, the reduced mean f_2/f_1 value for low frequency edge measures, compared to the mean value 2·00 for the high frequency edges, strongly supports the model of Wild, Murray, and Rowe (1954). In this model, slow drift bursts are generated by plasma oscillations in the solar corona, with complete absorption taking place below the plasma frequency.

The solar longitude observations extend and confirm the results of Roberts (1959) and of Maxwell, Thompson, and Garmire (1959). The observed lack of significant dependence upon longitude in either f_2/f_1 or in numbers of bursts occurring is not consistent with a spherically symmetrical corona. Such symmetry imposes severe limitations on the escape directions of the fundamental band. With increasing solar longitude more and more of the fundamental is cut off from a Sun-Earth path until f_1 is eliminated entirely beyond about 30° longitude. A mechanism is therefore necessary which will produce more nearly isotropic radiation. Roberts (1959, personal communication 1960) proposes a picture in which local irregularities in density provide this mechanism. In invoking such a model, two possibilities arise: either the irregularities act as scattering centres, scattering the fundamental into a Sun-Earth path, or local density condensations act as noise sources themselves and emit more or less isotropically. The latter case is attractive because of the association of slow drift bursts with ejected streams of solar corpuscles, expelled at times of flares. Such streams would provide the necessary density irregularities for wide-cone emission and thus permit observation of fundamental bands from non-central sources.

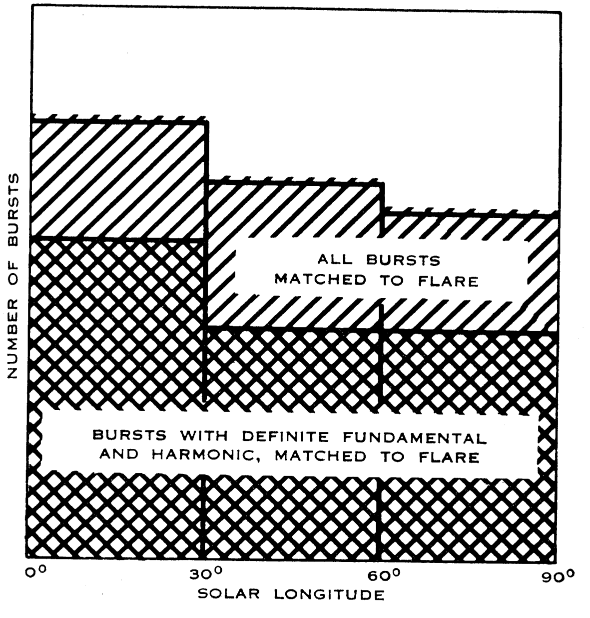

Fig. 4.—Centre-to-limb variation in burst occurrence.

III. Frequency Drift Rates of Slow Drift Bursts; Relation to Geomagnetic Disturbance

A priori, slow drift bursts would seem excellent candidates for association with geomagnetic storms: they are of great intensity; they are associated with flares of greater than average importance; and their velocities, inferred from frequency drift rates and assumed coronal model, are of the order of 1000 km/s, a value consistent with observed time intervals between flares and geomagnetic storms. However, when such bursts are related to magnetic disturbance level, the results are disappointing. Shown in Figure 5 (*a*) is a superposed epoch representation of mean geomagnetic index, *Ap*, on days before and after all slow drift bursts observed from October 1956 to September 1959 (88 cases). There is a tendency, although not marked, for an increase in geomagnetic activity on days 0–2 after the bursts. For comparison, in Figure 5 (*b*) is plotted the corresponding curve for geomagnetic disturbance level on days before and after outstanding continuum events which occurred during the same period (73 cases). In only seven cases were the continuum events and the slow drift bursts time associated within ± 1 hr; in only 20 cases were they as closely associated as ± 1 day. Thus the two samples are effectively independent. We see that the degree of association with geomagnetic activity is greater for the continuum events than for the slow drift bursts. It should be remarked that the only requirements placed on the continuum events in order to enter the sample are that they be classified, in the Fort Davis published data (National Bureau of Standards, F-Series, Part B 1956–1959), as "continuum", i.e. events with smoothly varying intensity, and that they be of importance $\geqslant 3$ and of duration

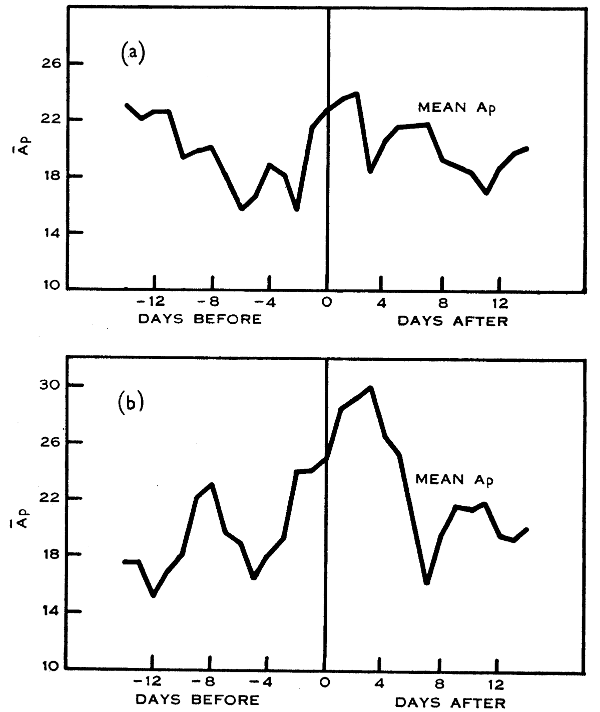

Fig. 5.—Geomagnetic disturbance level: (*a*) related to slow drift bursts and (*b*) to continuum events.

$\geqslant 5$ min. Thus the majority are not the fairly rare, wide band, long duration events referred to as type IV continuum, which McLean (1959) found associated with geomagnetic disturbance. Other studies of burst and continuum relations to geomagnetic disturbance have also been made by Maxwell, Thompson, and Garmire (1959).

Although no striking geomagnetic relation occurs in the case of the bursts, there does appear a degree of association, and it is of interest to try to find some burst characteristic, varying from event to event, which might differentiate between the storm and the non-storm producers. In this regard, frequency drift rates of the bursts are promising. The drift rates vary appreciably from burst to burst, and those events with fast frequency drifts may be related to noise sources with high outward velocities through the solar corona. Thus one would expect that the faster the frequency drift the greater the chance of escape from the Sun of the particles in the noise source and, thus, the greater the chance for magnetic disturbance.

Figure 6 (*b*) shows drift rates *v.* frequency for bursts followed by storm, while Figure 6 (*a*) shows the corresponding rates for bursts with no storm. The events entering the samples in Figure 6 are all observed slow drift bursts, October 1956–1959, which had well-defined and measurable frequency drift rates. Accord-

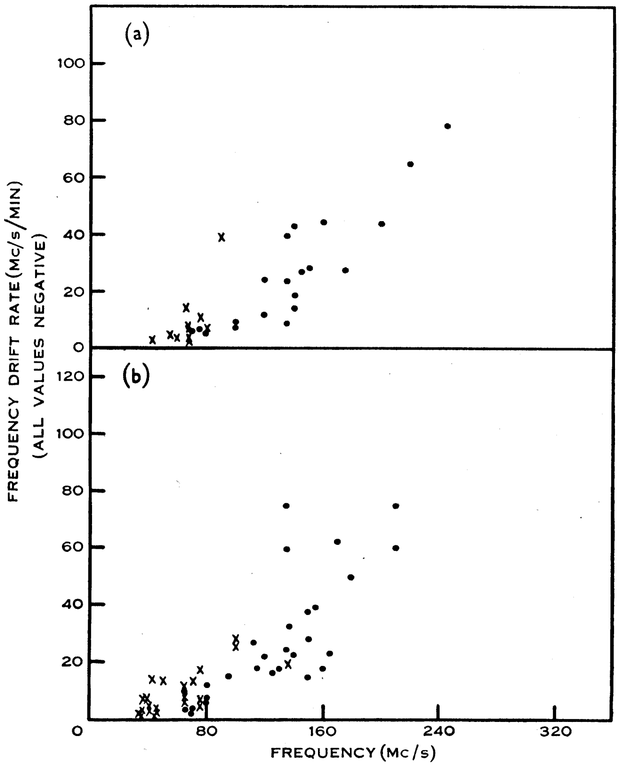

Fig. 6.—Frequency drift rates : (*a*) without storm, and (*b*) with storm. ● Harmonic, × fundamental.

ing to an earlier interpretation of Wood and Warwick (1959), based on the data going down only to 100 Mc/s, we should have expected the difference between storm and no storm drift rates to increase with decreasing frequency. However, the new lower frequency data do not bear out this expectation ; rather, there appears to be no definite difference between rates at either low or high frequencies.

In summary, the present results indicate that outstanding continuum events appear more strongly related to geomagnetic disturbance than do the slow drift bursts. Further, frequency drift rates of the bursts do not provide a means of distinguishing the storm-producing bursts from those not associated with geomagnetic disturbance.

IV. Acknowledgments

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