Letters

An Effect of a Transmitter Frequency Increase on the Occurrence of VLF Noise Triggered near $L = 3$ in the Magnetosphere

D. L. CARPENTER AND S. LASCH

Radioscience Laboratory
Stanford University, Stanford, California 94305

This report concerns the influence of transmitter frequency on the production in the magnetosphere of artificially stimulated VLF emissions (ASE). (For details of ASE, see *Helliwell et al.* [1964], *Helliwell* [1965], and *Kimura* [1967, 1968].) The VLF transmitter involved is NAA, which nominally radiates 10^6 watts and is located at Cutler, Maine, at a geomagnetic latitude of $\sim 56°$ and $L \sim 3.2$. The observations of ASE were made during the austral winters of 1963 and 1965 at Eights, Antarctica, roughly conjugate to NAA at $L \sim 4$. It was found that the number of observations of NAA-produced magnetospheric noise decreased markedly when the transmitter frequency was raised from 14.7 kHz to 18.6 kHz in early August 1963 and that when observations were made in 1965 with the transmitter at 17.8 kHz, the occurrence rate of ASE continued to be low.

This result is summarized in Figure 1, which shows the per cent of observing intervals with some detected ASE activity during: two broad sampling periods, one in 1963 and another in 1965, periods I and IV, respectively; two limited sampling periods in 1963, one before the NAA frequency increase (period II) and the other following the change (period III). A comparison of periods I and II with III and IV indicates a reduction of order 8:1 in activity after the increase in transmitter frequency.

The ASE for Figure 1 were scaled by visual identification on 35 mm frequency-time records. For 1963, the observing periods were 2 minutes hourly, while in 1965 they were 1 minute each 15 minutes. In 1963, the NAA transmissions were predominantly Morse code, while in 1965 both FSK (50-Hz frequency shift) and Morse code were used, with Morse code in 3 of 8 observing periods.

The sampling for 1965 (period IV of Figure 1) emphasized magnetic conditions similar to those obtained in 1963. Period III, in August 1963, represents conditions immediately after the initial increase in transmitter frequency to 18.6 kHz. Period II (early May 1963) was selected for comparison to period III on the basis of a similar temporal separation from the June solstice and roughly comparable magnetic conditions.

Some qualitative indication of the change in ASE activity is evident in the complexity and intensity of the triggered noises. An activity index was developed in which observed emissions were weighted on a subjective scale of 1 to 4 for intensity and complexity and 1 to 4 on the basis of the per cent of Morse code dashes during a run that triggered noise (1 for 0–25%, 2 for 25–50%, etc.). Thus a total of $4 + 4 = 8$ is the maximum number possible in a given 1 or 2-minute run. Using sums of these indices over a 24-hour period, it was found that in period I ($f_{NAA} = 14.7$ kHz), 35% of the days with ASE showed a sum of 10 or greater, whereas in period III ($f_{NAA} = 18.6$ kHz) *no* days showed a sum of 10 or greater, and in period IV ($f_{NAA} = 17.8$ kHz) only 1 day exceeded the 10 level. To emphasize this point, Figure 2 shows two examples of NAA-ASE spectra, one recorded during a period of extremely intense activity in 1963, and the other during one of the most active periods yet found in 1965. The spectral forms in the two cases are similar, but the 1963 event exhibits greater complexity and average intensity.

Comments on the Results

Several factors might contribute to the observed decrease in ASE activity. These include (1) changes in the observing system and in the transmission schedules; (2) changes in the excitation of magnetospheric paths due to latitudinal shift in typical path end points; (3) solar cycle effects on conditions for the production of ASE.

Instrumental-system effects are believed to be of negligible importance. Essentially the same recording equipment and system calibrations were used at Eights in both 1963 and 1965, and the lack of a strong instrumental effect is suggested by the drastic change in ASE activity from late July (period II) to early August of 1963 (period III). With respect to observing and transmitting schedules, the decreased number of Morse code transmissions in 1965 was approximately offset by the increased number (from 2 to 4 per hour) of observing minutes at Eights. (The FSK signals consist of combinations of 16-msec pulses at two fixed frequencies, 17.800 and 17.850 kHz.) At a given time, the probability of ASE production by FSK is less by a factor of 3 than the probability of triggering by Morse code dashes.

On the subject of path excitation, it was recently found that ASE are preferentially triggered along field lines whose equatorial gyrofrequency is within a few per cent of twice the transmitter frequency [*Carpenter*, 1968]. This tendency toward spatial limitation on triggering implies that with the increase in transmitter frequency from 14.7 to 17.8 kHz, the preferred path for ASE production by NAA moved to a field line with equatorial crossing about 0.2 R_E closer to the earth. In dipole coordinates this would involve a change from $L \sim 3.1$ to $L \sim 2.9$, with corresponding invariant latitude 55.4° in 1963 and 54.1° in 1965. The proximity of these latitudes to that of NAA, ~56° geomagnetic, calls attention to possible latitudinal variations in the illumination of the lower boundary of the ionosphere by the transmitter. However, ASE are known to propagate within available whistler ducts (unpublished research at Stanford), and randomness in the longitudes of these field-aligned ducts probably eliminates the importance of any small-scale path-illumination effect.

PERIOD NUMBER	f_{NAA}	OBSERVING PERIOD	% OF OBSERVING INTERVALS WITH SOME ASE ACTIVITY	
I	14 7 kHz	1963 71 DAYS MAY – JULY	14.5 % (MORSE CODE)	
II	14.7 kHz	1963 10 DAYS MAY 1–10	11 7% (MORSE CODE)	
III	18 6 kHz	1963 18 DAYS AUGUST 5–22	1 3% (MORSE CODE)	
IV	17 8 kHz	1965 27 DAYS JUNE — AUGUST	2 0% (MORSE CODE)	0.7% (FSK)

Fig. 1. Occurrence data indicating the decrease in observed artificial triggering of VLF magnetospheric noise associated with an increase in NAA transmitter frequency. The observations of triggered noise were made at Eights, Antarctica.

Explanations based on initiating signal intensity also suffer from the known dependence of NAA-ASE activity on the duration of the transmitted signal, viz. the predominance of Morse-code dashes over dots as triggering signals [*Helliwell et al.*, 1964; *Kimura*, 1967]. The relative unimportance of signal intensity is further evidenced by the frequent appearance of ASE after sunrise in the vicinity of the transmitter (I. Kimura, personal communication). These ASE are sometimes comparable in intensity to ASE produced under nighttime conditions, in spite of a ~20-db daytime increase in ionospheric absorption of the upgoing transmitted waves [*Helliwell*, 1965].

Attention is thus drawn to the propagation medium, and for example to solar cycle effects on the conditions for the production of ASE. Evidence of such effects may be sought in observations at Eights of ASE produced by the Forest Port, Omega transmitter, radiating ~100 watts at 10.2 kHz [*Kimura*, 1968]. Between 1963 and 1965, with transmitter frequency and nominal radiated power unchanged, the fractional number of observing days with Omega-associated ASE decreased by a factor of about 2, from 9 of 94 days in May–August 1963 to 4 of 76 days in June–August 1965. These results are most relevant to Omega paths near $L \sim 3.6$ and suggest that some small part of the NAA-ASE reduction may be a solar-cycle effect. Of course the Omega results fail to explain the

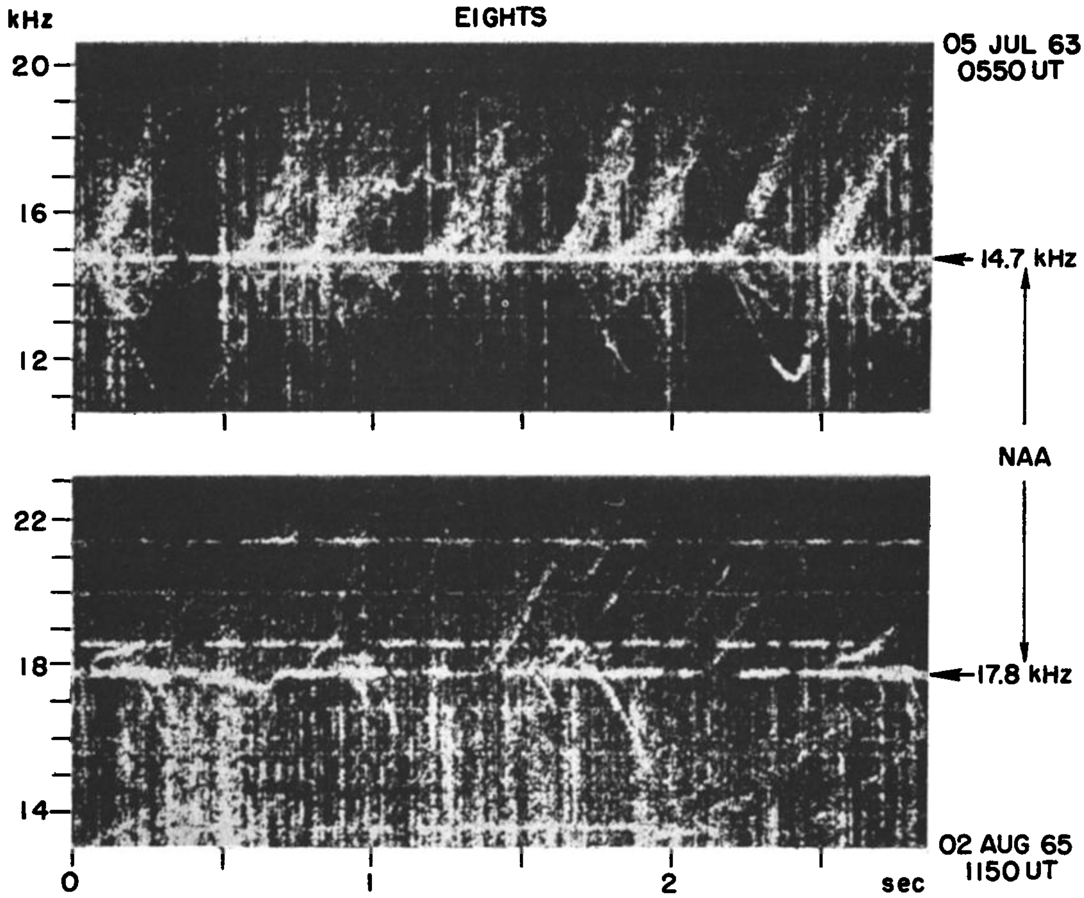

Fig. 2. Frequency-time spectra comparing periods of high ASE activity before and after the increase in NAA frequency from 14.7 to 17.8 kHz. The occurrence rate in 1963 of events similar to those in the upper panel was greater than the occurrence in 1965 of events similar to those in the bottom panel.

lower number of NAA-ASE in period III of 1963. For that period some part of the ASE reduction may be due to increases from July to August in total VLF absorption over a typical path.

Properties of the distribution of energetic electrons near $L = 3$ are probably involved in the phenomenon reported here. The inferred decrease in triggering path radius associated with the increase in NAA frequency may have occurred in a region of pronounced spatial and temporal variations of the 1–10 kev electrons capable of resonant interactions with the transmitted waves. The existence of a 'slot' near $L = 3$ in electrons of energy 100 kev and higher is well known [e.g. *Pfitzer et al.*, 1966; *Vernov et al.*, 1968, and references cited therein], and it may be that some counterpart of the slot is involved in the ASE effects. Both this possibility and the data themselves require further study.

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