

SOLAR EMISSION AT 10-CM WAVELENGTH

A. E. COVINGTON

*Radio and Electrical Engineering Division
National Research Council, Ottawa, Canada*

1. VARIATION OF DAILY FLUX THROUGH SUNSPOT CYCLE

The significance of 10-cm radio observations for studying the physical conditions in the lower corona of the solar atmosphere and for providing an index of solar activity comparable with the Zürich sunspot number is now well established. This radio emission from the solar disk has been observed daily at the Laboratories of the National Research Council of Canada in Ottawa since 1947, and the results interpreted in terms of a daily level of flux (near 17^h U.T.) and of bursts of noise that may appear during the day.

In the plot of monthly means for the past eleven-year period, shown in Fig. 1, it is interesting to note that the value for the present peak, 280 flux units, is about eight per cent higher than the 1947 value of 260, and is to be compared with the value of 68 units observed during the sunspot minimum of 1954. The original radio telescope and radiometer have been used and maintained consistently throughout this period, and it is believed that the

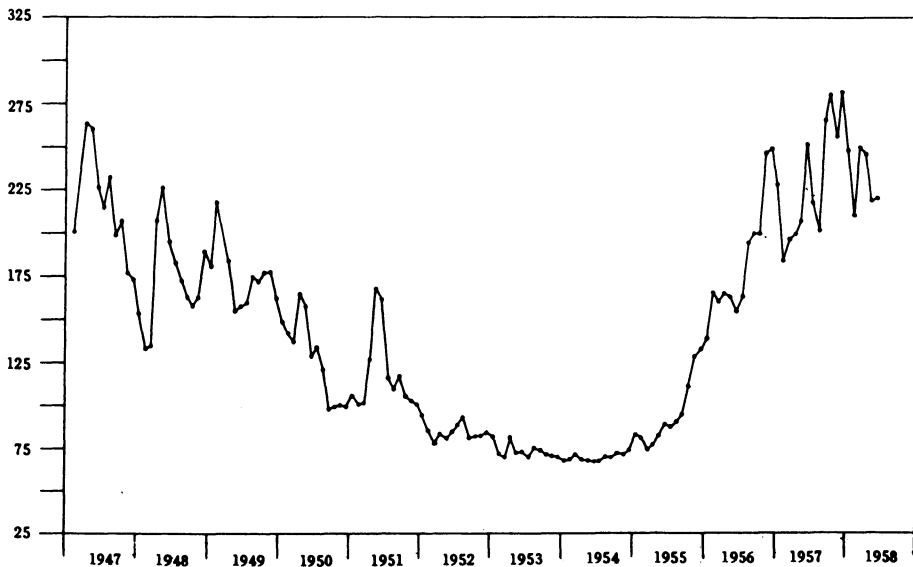


FIG. 1. Monthly averages of 10.7-cm solar flux, 1947-58.

relative error in the monthly measurements should not exceed three per cent [1].

2. BURST TYPES

The apparent simplicity of burst structure and the infrequency of occurrence of the 10-cm bursts have been noted before, and are in great contrast to the complexity and great abundance of bursts observed in the meter wavelengths. The bursts observed at Ottawa have been classified according to the basic types shown in Fig. 2. "Simple" bursts show a rise to a peak value and

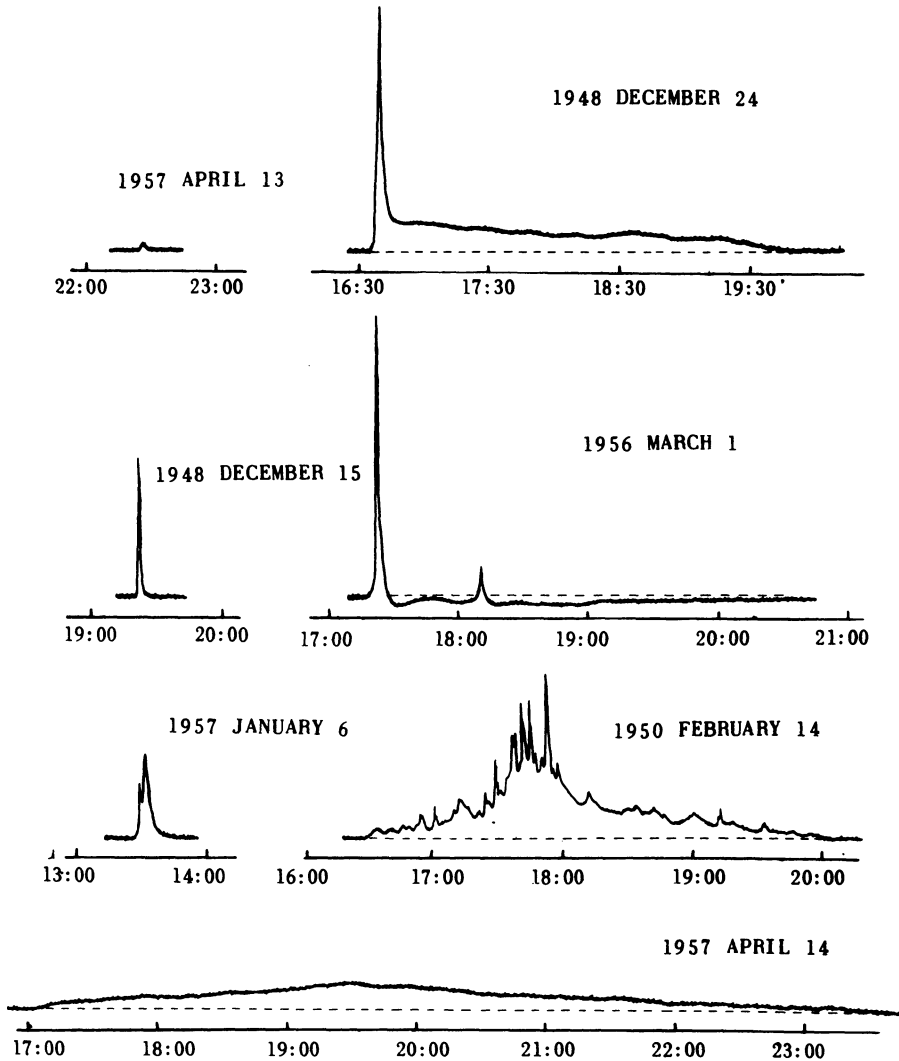


FIG. 2. 3000 Mc/s solar bursts: basic types.

a subsequent decline (example: 1957 April 13; 1957 April 14; 1948 December 15; 1948 December 24; 1956 March 1). "Complex" bursts show two or more significant peaks (1957 January 6), while many comparable bursts of small intensity occurring in rapid succession are grouped together into a "period of irregular activity" (1950 February 14). Although a significant number of simple and complex bursts do occur in groups, the individual members have been treated separately whenever possible, and the group of bursts has not been considered as representing a basic type. Sometimes the level of flux remains at an enhanced value for a considerable time after the burst has terminated (1948 December 24); such features are called "post-burst increases," and may follow simple or complex bursts. Another type of burst variation—a gradual diminution of flux occurring after an impulsive burst—reveals the presence of the absorptive rather than the emissive process. It is not frequent, and the example for 1956 March 1 shows a second small burst superimposed upon the absorptive feature.

3. IMPULSIVE BURSTS AND LONG-ENDURING BURSTS*

As an example of the frequency of occurrence of the simple bursts—that is, those that rise to one maximum and return to the pre-burst level—it is noted that approximately ninety per cent, or 600, of the total number of bursts recorded for 1956 were of this class. The remaining ten per cent have a complex structure with, for the most part, two or more peaks. The significant primary features of a simple burst are the intensity, the duration, and the rates of rise and fall. The first two of these cover a wide range: the intensity, from values barely discernible above receiver noise to thousands of units of flux; the duration, from a fraction of a minute to several hours. If a scatter diagram of intensity against duration is plotted, with a dot for each simple burst, an interesting feature is noted. This is illustrated by Fig. 3, in which such a scatter diagram is shown for the 600 simple bursts that occurred in 1956. The clustering of dots is not wholly random but shows a well-developed two-pronged distribution. This indicates the existence of two types of simple bursts that are basically different: one, an impulsive burst of relatively high intensity and short duration; the other, a long-enduring burst of relatively low intensity [2]. In the region of moderate intensity and duration, a random scatter is observed in which both types presumably appear together. Examination shows that in general the rate of rise for the simple bursts is greater than that of the fall.

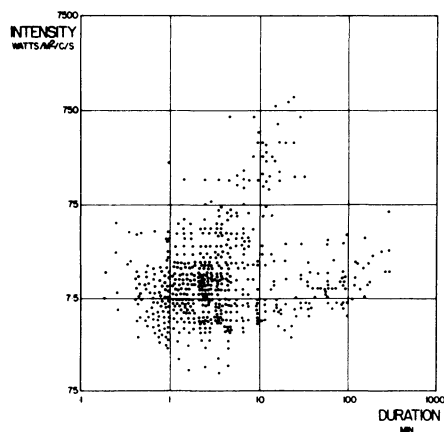


FIG. 3. Scatter diagram of simple bursts for 1956. Log of intensity versus log of duration.

* Also called "gradual rise and fall."

The ratio of the time taken to reach maximum to that of the total duration shows a variation from 0.1 to 0.5, with an average of 0.25 for the impulsive, and an average of 0.4 for the long-enduring bursts.

The obvious difference between the impulsive and the long-enduring bursts suggests that each reflects different physical processes of generating energy within the flare region. The ejection of particles and the emission of ultra-violet-light radiation are perhaps the two most fundamental processes indicated by geophysical studies of the aurora and the sudden ionospheric disturbances. It is tempting to suggest that the impulsive burst is generated by nonthermal processes related to the passage of highly energetic particles from the flare region, while the long-enduring burst is generated by thermal processes related to the heating of a localized region in the solar atmosphere. If so, the slowly varying component of solar flux, which is associated with the bright plages of hydrogen and calcium, and which has been regarded as a thermal emission from a condensation in the corona, should be considered a member of the class of long-enduring bursts. The great duration of several months and the intensity of several hundreds of flux units tend to make the point representing this enhancement lie on a hitherto unoccupied part of the scatter diagram. However, it falls on the general trend of the cluster of points that represents the long-enduring bursts, hence lending support to the suggestion that these bursts originate as short-lived sunspot regions. The varied association of the simple impulsive burst superimposed upon the simple long-enduring burst, if it originates in the same solar region, should aid in revealing the time of occurrence of particle emission in the lifetime of an active solar region.

4. COMPOUND INTERFEROMETER

The desirability of isolating the 10-cm radio-emissive regions that appear upon the solar disc, and of finding some of their physical properties, has led to the development of a 185-m linear array. The antenna pattern is fan-shaped, 2 degrees north-south by 1 minute of arc east-west, and is formed by means of phase-switching between a four-element grating and a continuous array of length equal to the grating gap. This arrangement of elements with connecting waveguide transmission lines is shown in Fig. 4. Antenna *A* is a 46-m V-shaped trough, 0.46 m wide, with a slotted rectangular 10-cm waveguide in the bottom [3]. This trough can be rotated about its long axis, which is in a level east-west direction, so that the radio telescope is used as a meridian telescope, with the sun drifting through the narrow part of the receiving pattern. The maximum of the beam in the narrow cross-section does not fall on the meridian, but may be placed at any hour angle from about 3 to 9 degrees east of the meridian by properly choosing the receiver frequency in a band ranging from 2770 to 3000 Mc/s. Antennas *B*₁, *B*₂, *B*₃, and *B*₄, in Fig. 4, are small parabolic cylinders, 3 m wide and 2.4 m long, with short sections of slotted waveguide at the focus which have characteristics similar to the slotted waveguide in the long array. The individual

elements have primary patterns of 3 degrees east-west by 2 degrees north-south, and will automatically receive energy at the same hour angle as the array beam. All five units, however, must be adjusted mechanically in order to have the same elevation. The feature of shifting the resultant beam in hour angle by changing the frequency of reception has proven valuable, and instrumentation has been developed to take four drift-curves each day. This involves the successive use of two local oscillators in the superheterodyne receiver, with reception occurring separately, first on the higher frequency sideband, and then on the lower frequency sideband of the respective oscillator.

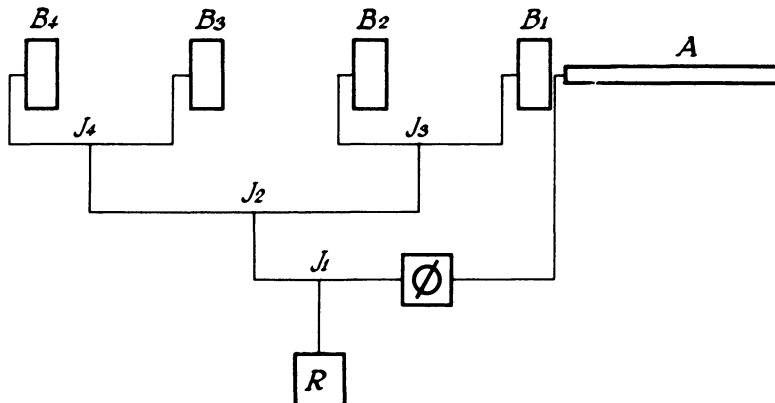


FIG. 4. Diagram of interferometer elements and waveguide transmission lines.

A rotary phase-shifter is operated in the waveguide transmission line between the array and the grating and introduces a linear change of phase between the voltages induced in the two antennas at 15 cycles per second. After amplification and rectification, a 15-cycle synchronous detector separates the average fluctuating power from the mean power and gives the desired single-lobed antenna pattern as a product of three terms. The alignment of the maxima of these three patterns—the single-lobed array pattern, the multi-lobed grating pattern, and a cosine interference pattern related to the separation of the phase centers of the grating and array—must be made by experiment. Adjustments in frequency and in phase are made over a period of time, with the sun serving as a reference object. The satisfactory operation of this interferometer system with two antennas has been described before [4]. Though there was a fourfold increase in resolution compared with the operation of the long array, the results showed that the receiving pattern was not sufficiently sharp to resolve the radio sunspots. Consequently, consideration was given to applying the principle to a longer antenna. The extended compound interferometer with five elements was constructed, and preliminary tests were commenced in 1958 May.

The junctions in the waveguide transmission line contain switches to connect the receiver to any one of the elements separately or in various paired combinations. The electrical length to each grating element was measured from

the minimum of the standing wave pattern produced by reflection from a short placed at the antenna; the feeder lengths were adjusted to equality by dielectric phase-shifters in the various waveguide transmission lines. As previously mentioned, the frequency of operation and relative phase between array and grating must be found experimentally by observing the sun. Other changes in the electrical characteristics related to the temperature of the antenna are in the process of being evaluated.

5. HIGH RESOLUTION DRIFT CURVES

Four drift curves for 1958 June 28 were obtained during a period of antenna alignment, and are shown in Fig. 5; they were obtained (a) with the array alone, (b) with the array and the nearer single-grating element, (c) with the array and two elements, and (d) with the array and four elements. The ap-

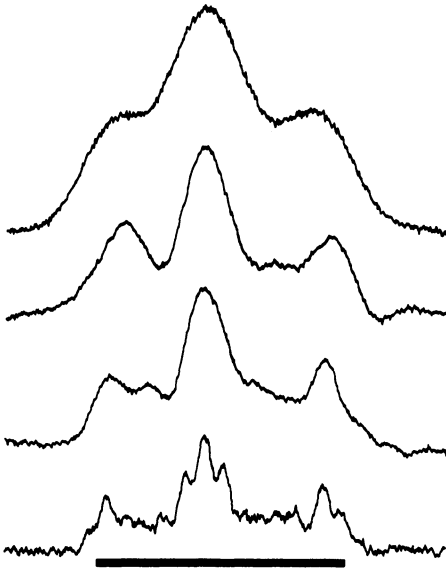


FIG. 5. Drift curves of sun, 1958 June 28. Approximate east-west beamwidths are respectively 8, 4, 2, and 1 minute of arc.

proximate east-west beamwidths produced by these various antennas are, respectively, 8, 4, 2, and 1 minutes of arc. The three narrowest antenna patterns tend to approximate the shape of the optimum antenna pattern given by the function $(\sin x)/x$, while the first pattern in the series approximates the square of the same function. With the successive use of these fan-shaped antenna patterns, the separation of the three radio-emissive sunspot regions from the solar background becomes increasingly more prominent.

It is interesting to see that ultimately the central region becomes resolved into a strip about six minutes of arc wide, while the two regions on either limb still present half-power widths about fifty per cent wider than expected from a point source. The interpretation of this half-power width as a source dimension, with the aid of

the theoretical antenna pattern, indicates that these regions have an east-west width of about two minutes of arc. The flat region between the three prominent ones contains other small spots that are somewhat lost in the residual receiver noise. The extent of the visible photospheric disk, $31'32''$, is shown as a line.

The series of drift curves from 1958 June 27 to July 1 (Fig. 6) shows the effect of solar rotation and of the rapidly changing features upon the solar disk. On June 28, a long-enduring burst, lasting five hours, with a peak flux of 23×10^{-22} watts $m^{-2}(c/s)^{-1}$, was observed with other equipment recording

the total flux, and showed no change in intensity during the half-hour required to obtain the four drift curves. This event was undoubtedly located in the prominent central region seen in the drift curve for this day, and consequently the central profile is of spot and burst (at 16^h46^m U.T.). Perhaps in view of the unknown extent of the emitting area in the north-south direction, and the confusion of burst dimensions with other preexisting spots, any estimated temperature value should be regarded only as a limit. If the shape of the long-enduring burst is regarded as circular, its diameter corresponding to the maximum observed width of six minutes of arc, a lower limit to the equivalent temperature of 0.4×10^6 °K may be calculated from the burst intensity. If the long-enduring bursts are to be regarded as manifestations of a short-lived coronal condensation, as suggested previously, this temperature value, although reasonable, is low by a factor of four in comparison with a coronal condensation temperature of 1.5×10^6 °K.

The drift curves for the two days after the long-enduring burst of June 28 show several spots placed upon a uniformly raised level. This has been taken as an indication of the undisturbed solar disk for the period, and measures 8 per cent wider than the photospheric disk. The extent of the photosphere in Fig. 6 is indicated by the ruled lines.

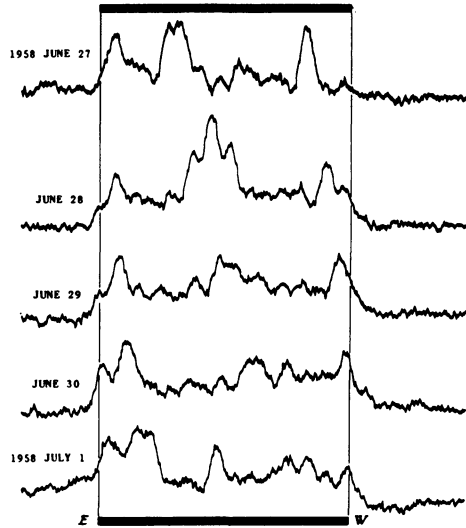


FIG. 6. Series of uncalibrated drift curves, 1958 June 27 to 1958 July 1, showing effect of solar rotation and decay of prominent central region occurring on June 28.

REFERENCES

- [1] Medd, W. J., and Covington, A. E. *Proc. I.R.E.* **46**, 112, 1958.
- [2] Covington, A. E., and Harvey, G. A. *J.R.A.S. Can.* **52**, 161, 1958.
- [3] Covington, A. E., and Broten, N. W. *Ap. J.* **119**, 569, 1954.
- [4] Covington, A. E., and Broten, N. W. *Trans. IRE/PGAP*, Vol. AP-5, 247, 1957.