1971

An analysis of solar noise outbursts and their application to space communication

Marion Francis Moen

Follow this and additional works at: http://scholarsmine.mst.edu/masters_theses

Recommended Citation

This Thesis - Open Access is brought to you for free and open access by the Student Research & Creative Works at Scholars' Mine. It has been accepted for inclusion in Masters Theses by an authorized administrator of Scholars' Mine. For more information, please contact weaverjr@mst.edu.
AN ANALYSIS OF SOLAR NOISE OUTBURSTS

AND THEIR APPLICATION TO SPACE COMMUNICATION

BY

MARION FRANCIS MOEN, 1935-

A THESIS

Presented to the Faculty of the Graduate School of the

UNIVERSITY OF MISSOURI-ROLLA

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

1971

Approved By

[Signatures]
Title of Thesis:
An Analysis of Solar Noise Outbursts and Their Application to Space Communication

Abstract:
A relationship between sunspot activity, solar flare activity and noise outbursts is presented. Five different types of interference radiation in the 10MHz to 30,000 MHz frequency band are discussed.

Data obtained by solar radio astronomy are analyzed to determine the extent of solar noise outbursts as a function of sunspot activity. An application of the burst data to future space communication is given.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>LIST OF ILLUSTRATIONS</td>
<td>iv</td>
</tr>
<tr>
<td>I. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>II. REVIEW OF LITERATURE</td>
<td>3</td>
</tr>
<tr>
<td>III. SOLAR STRUCTURE, SUNSPOT ACTIVITY AND FLARES</td>
<td>4</td>
</tr>
<tr>
<td>A. Solar Structure</td>
<td>4</td>
</tr>
<tr>
<td>B. Sunspot Activity</td>
<td>4</td>
</tr>
<tr>
<td>C. Solar Flare Activity</td>
<td>7</td>
</tr>
<tr>
<td>IV. OBSERVED SOLAR RADIO NOISE</td>
<td>9</td>
</tr>
<tr>
<td>A. Equivalent Thermal Radiation</td>
<td>9</td>
</tr>
<tr>
<td>B. Quiet Sun Radiation</td>
<td>9</td>
</tr>
<tr>
<td>C. Disturbed Sun Radiation</td>
<td>9</td>
</tr>
<tr>
<td>V. ANALYSIS OF SOLAR NOISE BURST DATA</td>
<td>15</td>
</tr>
<tr>
<td>A. Noise Bursts and Space Communication</td>
<td>15</td>
</tr>
<tr>
<td>B. Solar Noise Bursts as a Function of Sunspot Activity</td>
<td>16</td>
</tr>
<tr>
<td>C. Burst Duration</td>
<td>31</td>
</tr>
<tr>
<td>VI. APPLICATION OF BURST DATA TO SPACE COMMUNICATION</td>
<td>34</td>
</tr>
<tr>
<td>A. Spacecraft Rendezvous</td>
<td>34</td>
</tr>
<tr>
<td>B. Interplanetary Space Communication</td>
<td>37</td>
</tr>
<tr>
<td>VII. CONCLUSIONS</td>
<td>39</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>40</td>
</tr>
<tr>
<td>VITA</td>
<td>41</td>
</tr>
</tbody>
</table>
### LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Smoothed Zurich Sunspot Number, R, From 1754 to 1970</td>
<td>6</td>
</tr>
<tr>
<td>2. Smoothed Zurich Sunspot Number, R, Showing a 3 Month Periodicity</td>
<td>6</td>
</tr>
<tr>
<td>3. Solar Noise Bursts, N, Greater Than 100×10^{-22} WM^{-2}Hz^{-1} with the Actual and Predicted Zurich Sunspot Number</td>
<td>8</td>
</tr>
<tr>
<td>6. Idealized Radio Noise Spectrum of a Major Solar Outburst</td>
<td>14</td>
</tr>
<tr>
<td>7. Solar Bursts per 1000 Hours Having Power Density Peaks Greater Than 100×10^{-22} WM^{-2}Hz^{-1} (1966)</td>
<td>17</td>
</tr>
<tr>
<td>8. Solar Bursts per 1000 Hours Having Power Density Peaks Greater Than 100×10^{-22} WM^{-2}Hz^{-1} (1967)</td>
<td>18</td>
</tr>
<tr>
<td>9. Solar Bursts per 1000 Hours Having Power Density Peaks Greater Than 100×10^{-22} WM^{-2}Hz^{-1} (1968)</td>
<td>19</td>
</tr>
<tr>
<td>10. Solar Bursts per 1000 Hours Having Power Density Peaks Greater Than 100×10^{-22} WM^{-2}Hz^{-1} (1969)</td>
<td>20</td>
</tr>
<tr>
<td>11. Solar Bursts per 1000 Hours Having Power Density Peaks Greater Than 100×10^{-22} WM^{-2}Hz^{-1} (1970)</td>
<td>21</td>
</tr>
<tr>
<td>12. Bursts per 1000 Hours as a Function of Power Density (245 MHz)</td>
<td>23</td>
</tr>
<tr>
<td>13. Bursts per 1000 Hours as a Function of Power Density (606 MHz)</td>
<td>24</td>
</tr>
<tr>
<td>14. Bursts per 1000 Hours as a Function of Power Density (1415 MHz)</td>
<td>25</td>
</tr>
<tr>
<td>15. Bursts per 1000 Hours as a Function of Power Density (2695 MHz)</td>
<td>26</td>
</tr>
</tbody>
</table>
List of Illustrations (continued)

<table>
<thead>
<tr>
<th>Image</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.</td>
<td>Bursts per 1000 Hours as a Function of Power Density (4995 MHz)</td>
<td>27</td>
</tr>
<tr>
<td>17.</td>
<td>Bursts per 1000 Hours as a Function of Power Density (8800 MHz)</td>
<td>28</td>
</tr>
<tr>
<td>18.</td>
<td>Bursts per 1000 Hours as a Function of Power Density (15,400 MHz)</td>
<td>29</td>
</tr>
<tr>
<td>19.</td>
<td>Monthly Zurich Sunspot Number and 606 MHz Burst Activity for the 1966 Through 1970 Interval</td>
<td>30</td>
</tr>
<tr>
<td>20.</td>
<td>Burst Durations for Bursts Greater Than $100 \times 10^{-22}$ WM$^{-2}$Hz$^{-1}$ Above Background Radiation</td>
<td>32</td>
</tr>
</tbody>
</table>
I. INTRODUCTION

In the design and operation of long-distance radio communication systems the maximum range of operation is constrained by the signal-to-noise level required for satisfactory data reception. Signal strength at the receiver detector depends upon system parameters resulting from design selections and also upon the distance over which the transmitted signal travels. The noise level present at the receiver detector depends upon the amount of noise generated within the receiver and also on noise generated externally.

When the communication system performance is initially analyzed, the receiver signal to noise margins are found from measurements or calculations involving system parameters and internally generated noise. A maximum theoretical range can then be found where the minimum acceptable signal-to-noise ratio occurs.

The analysis can be expanded to include anticipated effects of externally generated noise. This noise, broadly classified as terrestrial and extraterrestrial, has been extensively studied and estimates of their location and intensity has been recorded (1). Noise levels at the receiver detector due to these sources can be readily calculated and the effects on the maximum theoretical operating range determined.
The noise from one of these sources, the sun, has not been adequately evaluated. A considerable amount of solar astronomy data is available to show that solar noise bursts can be as great as four orders of magnitude above quiet sun noise levels. The number of times the noise bursts can be expected in any time interval, the duration of these bursts and their relation to the sunspot cycle have not been adequately analyzed. This thesis will present a method for determining the extent of noise activity as a function of the sunspot cycle and illustrate an application of the data to future space communication usage.
II. REVIEW OF LITERATURE

The analysis presented by Mingo (1) provides some probability of occurrence data for solar noise interference. This probability of occurrence data does not include information relating to sunspot activity or noise occurrence probability for levels above or below a fixed value.

Numerous solar astronomy textbooks and articles were reviewed. Many of these contained data relating to specific levels of activity for discrete noise types. No publications were found which presented detailed analysis of solar noise interference.
III. SOLAR STRUCTURE, SUNSPOT ACTIVITY AND FLARES

A. Solar Structure. When the sun is viewed through appropriate filters, without the aid of magnification, it appears as a quietly radiating sphere. This readily visible region is called the photosphere. At the average earth-sun distance of $1.5 \times 10^8$ Km (one Astronomical Unit, AU) the $1.4 \times 10^6$ Km diameter of this region subtends an angle of 0.53 degrees. The photosphere is the lowest of three readily identifiable regions. The middle region, or chromosphere, extends from the upper boundary of the photosphere for about $2 \times 10^4$ Km. The third region, the corona, begins at the upper end of the chromosphere and extends far out into interstellar space. The electron temperature of the corona is estimated to be around $10^6^\circ K$. The effective temperature of the complete solar structure is about $5800^\circ K$ (2).

When the sun is viewed through a telescope with appropriate filters, numerous irregularities and some occasional violent activity can be observed in the three regions. Two of these activities, sunspots and solar flares, have been identified by many observers such as Kraus (3), Dodson (4) and O'Brien (5) to be directly related to solar noise outbursts.

B. Sunspot Activity. Sunspots are characterized by the appearance of dark spots and patches on the
photosphere. Sunspots are believed to be cooler regions of the photosphere and can be easily observed through protective filters passing the visible "white light" spectrum. The darker inner part of the spot (umbra) is surrounded by a lighter region (penumbra). Large, bright areas (plages) frequently surround the entire sunspot.

Solar sunspot activity follows a basic period of about 11.05 years. The magnetic polarity associated with sunspots shows a reversal between the solar hemispheres at the minimum activity point of the 11 year cycle. This reversal indicates an actual period of 22.1 years, as shown in figure 1. A long-term variation of between 78 to 88 years can also be observed. Shorter periodicities of three months have been detected and can be seen in figure 2 (3). A 27 day periodicity, thought to be caused by solar rotation, is also present. Solar activity models, derived from past sunspot data, enable reasonably accurate predictions of sunspot activity to be made (6).

Sunspot activity is generally expressed in terms of the Zurich (or Wolf) sunspot number $R$, where:

$$ R = k(10g + f) $$

- $k$ = an "observer" factor
- $g$ = number of observed sunspot groups
- $f$ = number of individual spots showing umbrae
Figure 1. Smoothed Zurich Sunspot Number $R$, From 1754 to 1970.

Figure 2. Smoothed Zurich Sunspot Number, $R_s$, Showing a Three-Month Periodicity.
The Zurich sunspot number is usually smoothed over the 27 day solar rotation period. The Zurich sunspot number for the 1965 to 1971 interval, with the predicted 1972 to 1976 activity, is presented in figure 3 (6).

C. Solar Flare Activity. Solar flares appear as short lived (0.3 to 3 hours) sudden bursts of light, generally originating within the plage region of sunspot activity. Flares are most easily observed when using a filter passing the spectral emission line of neutral Hydrogen (Hα). Flares are classified according to importance on a scale of 1− (indicating a subflare), 1, 2, 3 and 3+ (indicating a major outburst). Flares with a classification of 1 or higher will develop at a rate roughly \( R/25 \) times per day (7). Because of the relationship between sunspots, flares and noise outbursts it is possible that on a day when \( R = 100 \), four flares with associated noise outbursts could occur. In general, the major noise outbursts, with power density increases of 3 to 4 orders of magnitude above background levels are caused by class 3+ flares which occur infrequently.
Figure 3. Solar Noise Bursts, \( N \), Greater Than \( 100 \times 10^{-22} \text{Wm}^{-2} \text{Hz}^{-1} \) with the Actual and Predicted Zurich Sunspot Number, \( R \).
IV. OBSERVED SOLAR RADIO NOISE

A. Equivalent Thermal Radiation. Solar radiation data obtained with radio telescopes follow Planck's radiation law for blackbody radiation (from a 5800°K source) for radiation frequencies greater than about 300GHz. Below 300GHz, the radio noise increases and reaches an equivalent blackbody maximum temperature of about 10^6°K in the 30MHZ to 80MHZ region during periods of low sunspot activity. During periods of high sunspot activity the equivalent blackbody temperature in this frequency range may increase to about 10^10°K.

B. Quiet Sun Radiation. Quiet sun radiation occurs when little or no sunspot activity is present, usually during a solar sunspot cycle minimum. Figure 4 shows quiet sun radiation power density as a function of frequency for the sunspot minimum of 1964 (8).

C. Disturbed Sun Radiation. Disturbed sun radiation consists of two components, the slowly-varying and the rapidly-varying (burst) radiation.

Maximum values of the slowly-varying component, or background radiation is shown in curve (b) of figure 4 for the 1969 sunspot maximum.

The rapidly-varying component consists of bursts, or groups of bursts, lasting from a few seconds to several hours. These bursts cover the radio frequency spectrum between 5MHZ and 30,000MHZ and produce peak power density
Figure 4. Background Solar Noise Radiation During the 1964 Sunspot Minimum and 1969 Sunspot Maximum.
increases from 1,000 to 10,000 times the background radiation level. The amplitude-time curves of figure 5 show the irregular nature and large increases in power density associated with a major outburst (9).

Burst activity has been found to consist of five noise radiation types (3). They are:

- Type I - noise storm bursts
- Type II - slow-drift bursts
- Type III - fast-drift bursts
- Type IV - broad-band continuum emission
- Type V - meter wavelength continuum emission

Type I noise radiation occurs in the frequency range of approximately 50MHz to 400MHz. This radiation consists of a background level 3 to 10 times the quiet-sun levels shown in figure 4. Superimposed on this background are large numbers of short-duration (less than one second) discrete frequency outbursts. One hundred bursts per minute are often observed in the 205 MHz to 230MHz frequency interval. Peak power densities, expressed in terms of watts per square meter per unit cycle of bandwidth (Wm^-2Hz^-1), are usually around twice the background level, but have been observed up to ten times as great (10).

Type II radiation is identified by its 20MHz per minute frequency drift from higher to lower frequencies. These bursts generally appear in the 25MHz to 500MHz frequency interval. The instantaneous bandwidth of a burst is approximately 40 percent of its center frequency. Power density increases of up to 10,000 times
Figure 5. Power Density Variations During the Great Burst of 23 May, 1967, observed at the Sangamore Hill Radio Observatory, Hamilton, Massachusetts.
the background radiation level have been recorded during these bursts.

Type III radiation is similar to Type II radiation, except that the drift rate (20 MHz per second) is approximately 60 times faster and the bursts are observed up to 600 MHz. Power density increases during Type III bursts are also as great as 10,000 times the background radiation.

Type IV bursts are broad-band, stable radiations covering the 10 MHz to 30,000 MHz frequency range. These bursts last from a few minutes to several hours, with power density peaks of up to 10,000 times the background level.

Type V bursts are broad-band emissions in the 10 MHz to 300 MHz and 1,000 MHz to 15,000 MHz frequency intervals. These bursts exist for one to three minutes. Peak power densities of up to 100 times the background level have been recorded.

An idealized spectrum of a major outburst showing the different radiations and their approximate time of occurrence is presented in figure 6 (3). Several periods of intense noise radiation can be expected to occur at any discrete frequency due to the various burst types.
Figure 6. Idealized Radio Noise Spectrum Of a Major Solar Outburst.

Kraus (3)

Time in Minutes From Burst Initiation
V. ANALYSIS OF SOLAR NOISE BURST DATA

A. Noise Bursts and Space Communication. If a long distance space communication system is required to operate with a low signal-to-noise ratio when the antenna pattern falls within the 0.53 degree solar disk, it is possible that a solar noise burst will cause communication interference. The extent of the interference will depend upon the magnitude and duration of the received solar noise power density. The significance of the disruption will depend upon the subsequent actions required to correct problems resulting from data not being communicated at the proper time.

To obtain a better understanding of the number of times and duration that solar noise power density could exceed specified levels, data recorded by the Sangamore Hill Radio Observatory for the 1966 to 1971 sunspot interval were analyzed (9). During this interval the sunspot cycle went from minimum to maximum activity. Data recorded by the Sangamore Hill Observatory consist of start times and durations, peak power density above background levels and average power densities of all measurable bursts at 245MHz, 606MHz, 1415MHz, 2695MHz, 4995MHz, 8800MHz, and 15,400MHz.¹

¹245MHz data were not recorded prior to February, 1969
15,400MHz data were not recorded prior to January, 1968
4,995 MHz data were not recorded prior to January, 1966
The data are recorded from sunup to sundown each day, for a total observed time of 800 to 1300 hours per quarter year. The burst power density is measured with reference to the background level and is corrected to a distance of one Astronomical Unit from the sun. These data were analyzed to determine:

1. The number of noise bursts per 1,000 hours which exceeded 100, 200, 400, 800, 2,000, 4,000 and 8,000 times a base level of $10^{-22}$ watts per square meter per unit cycle of bandwidth ($Wm^{-2}Hz^{-1}$) at the seven test frequencies.

2. The minimum, maximum and average duration that the bursts exceeded $100 \times 10^{-22} Wm^{-2}Hz^{-1}$ (at the seven test frequencies) during 1970.

B. Solar Noise Bursts as a Function of Sunspot Activity.

The number of bursts exceeding the seven specified power levels were recorded over three-month intervals. Since observation times were between 800 and 1,300 hours for the three-month intervals, totals were normalized to 1,000 hours.

The number of bursts with peaks exceeding $100 \times 10^{-22} Wm^{-2}Hz^{-1}$ have been plotted as a function of frequency. These data are presented in figures 7 through 11 for the sunspot activity from 1966 through 1970. Minimum burst activity appears to be located at about $2,000MHz$ with peak activity occurring at or below $245MHz$. 
Figure 7. Solar Bursts Per 1,000 Hours Having Power Density Peaks Greater Than $100 \times 10^{-22} \text{Wm}^{-2} \text{Hz}^{-1}$ (1966).
Figure 8. Solar Bursts Per 1000 Hours Having Power Density Peaks Greater Than $100 \times 10^{-22} \text{Wm}^{-2} \text{Hz}^{-1}$ (1967).
Figure 9. Solar Bursts Per 1000 Hours Having Power Density Peaks Greater Than 100 \times 10^{-22} \text{Wm}^{-2}\text{Hz}^{-1} (1968).
Figure 10. Solar Bursts Per 1000 Hours Having Power Density Peaks Greater Than 100x10^{-22} W m^{-2} Hz^{-1} (1969).
Figure 11. Solar Bursts Per 1000 Hours Having Power Density Peaks Greater Than $100 \times 10^{-22} \text{Wm}^{-2} \text{Hz}^{-1}$ (1970).
The number of bursts per 1,000 hours have been plotted as a function of power density for the seven test frequencies, and are presented in figures 12 through 18. Results of these plots indicate that the number of bursts, N, appear to decrease approximately as a function of the inverse of the power density, D, raised to a fractional exponent, or

$$N = \frac{C}{D^a}$$

Where C is a constant. $0.6 \leq a \leq 1.0$

The average value of the normalized burst numbers from figures 7 through 11 have been plotted in figure 3 to illustrate burst activity as a function of sunspot number. These curves show that burst activity is roughly proportional to the Zurich sunspot number. In the 1966-1971 interval, when the Zurich sunspot number increased from approximately 55 to approximately 110, the normalized burst number (for bursts greater than $100 \times 10^{-22} \text{Wm}^{-2}\text{Hz}^{-1}$) increased roughly by a factor of two. The decrease in burst activity shown for certain lower frequencies during 1969 appear to be offset by an increase in activity for some of the higher frequencies.

The three-month periodicity in the smoothed Zurich sunspot number during the 1954 to 1958 interval (shown in figure 2) is also evident in the 1966 to 1970 sunspot interval, shown in figure 19. Burst activity during the 1966 to 1970 interval, also shown in figure 19, can be seen to fluctuate with an approximate three-month
Figure 12. Bursts Per 1000 Hours as a Function of Power Density (245 MHz)

Curve (a) - 1970
Curve (b) - 1969
Curve (c) - 1966 (estimated)
Figure 13. Bursts Per 1000 Hours as a Function of Power Density (606 MHz)

Power Density Above Background Level, D (Wm$^{-2}$Hz$^{-1}$)

- Curve (a) - 1970
- Curve (b) - 1969
- Curve (c) - 1968
- Curve (d) - 1967
- Curve (e) - 1966
Figure 14. Bursts Per 1000 Hours as a Function of Power Density (1415 MHz)
Figure 15. Bursts Per 1000 Hours as a Function of Power Density (2695 MHz

- Curve (a) - 1968
- Curve (b) - 1969
- Curve (c) - 1970, 1967
- Curve (d) - 1966
Figure 16. Bursts Per 1000 Hours as a Function of Power Density (4995 MHz)

- Curve (a) - 1970
- Curve (b) - 1969, 1968
- Curve (c) - 1967
Figure 17. Bursts Per 1000 Hours as a Function of Power Density ($8800 \text{ MHz}$).

Curve (b) - 1966
Curve (a) - 1969
Curve (b) - 1970 and 1968

Figure 18. Bursts Per 1000 Hours as a Function of Power Density ($15,400 \text{MHz}$)
Figure 19. Monthly Zurich sunspot Number, and 606 MHz Burst Activity for the 1966 Through 1970 Interval.
periodicity. Months where considerable burst activity occurs are followed by months where little or no activity is present, even during the 1968 to 1970 sunspot maxima. Some correlation between sunspot peak and burst peak activity can be seen.

C. Burst Duration. The data presented in figures 7 through 18 provide an estimate of the number of times solar noise burst radiation could possibly cause space communication interference. The period of interference will depend upon the duration of the solar disturbance causing the solar noise radiation.

To obtain a better understanding of the length of bursts, the burst duration times for bursts greater than $100 \times 10^{-22} \text{Wm}^{-2} \text{Hz}^{-1}$ for the seven test frequencies, over the entire 1970 observation time were divided into 16 duration categories. The duration times are shown in figure 20, along with a column for the longest burst duration recorded during 1970. The duration data apply only for burst power density exceeding $100 \times 10^{-22} \text{Wm}^{-2} \text{Hz}^{-1}$ above background levels. Figure 5 shows that the $100 \times 10^{-22} \text{Wm}^{-2} \text{Hz}^{-1}$ power density level at 8,800 MHz was exceeded for 112 minutes. This length, which applies only to this particular burst, correlates with the tabulated duration shown for this burst in the USAF (CRL) data (9). Burst power density levels in figure 5 that are higher than the baseline $100 \times 10^{-22} \text{Wm}^{-2} \text{Hz}^{-1}$ are not exceeded for the total time of the disturbance due to the
<table>
<thead>
<tr>
<th>Frequency, MHz</th>
<th>0 to .25</th>
<th>.25 to .50</th>
<th>.50 to 1</th>
<th>1 to 2</th>
<th>2 to 4</th>
<th>4 to 6</th>
<th>6 to 8</th>
<th>8 to 10</th>
<th>10 to 15</th>
<th>15 to 20</th>
<th>20 to 30</th>
<th>30 to 40</th>
<th>40 to 50</th>
<th>50 to 60</th>
<th>60 to 120</th>
<th>120 to 180</th>
<th>Maximum Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>15400</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>9</td>
<td>6</td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>301</td>
</tr>
<tr>
<td>8800</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>8</td>
<td>15</td>
<td>10</td>
<td>6</td>
<td>11</td>
<td>5</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>117</td>
<td></td>
</tr>
<tr>
<td>4995</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>7</td>
<td>10</td>
<td>5</td>
<td>15</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>2695</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>4</td>
<td>11</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>197</td>
</tr>
<tr>
<td>1415</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>3</td>
<td>11</td>
<td>5</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>230</td>
</tr>
<tr>
<td>606</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>14</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>12</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>238</td>
</tr>
<tr>
<td>245</td>
<td>1</td>
<td>5</td>
<td>12</td>
<td>20</td>
<td>22</td>
<td>16</td>
<td>12</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>283</td>
</tr>
</tbody>
</table>

Figure 20. Burst Durations For Bursts Greater Than $100 \times 10^{-22} \text{Wm}^{-2} \text{Hz}^{-1}$ Above Background Level (1970).
irregular burst shape. If the data from figures 12 through 18 are used to predict burst activity at various power densities it should be remembered that the median duration of bursts exceeding levels higher than $100 \times 10^{-22}$ Wm$^{-2}$Hz$^{-1}$ will be less than the median values obtained from figure 20. Special recording techniques and analysis are required to determine the exact amount of time the noise power density exceeds various levels. These techniques were not employed during the past observation periods and the data are not available.

From the data in figure 20, the median burst duration appears to be between approximately 4 to 10 minutes. Burst activity at 245MHz appears to have some of the shortest and longest durations; six bursts between 0 and 0.5 minutes and one burst lasting for 283 minutes.
VI. APPLICATION OF BURST DATA TO SPACE COMMUNICATION

A. Spacecraft Rendezvous. One rendezvous technique considered for use in the NASA Skylab program requires the Orbiting Workshop (target vehicle) to be illuminated by the sun to allow visual acquisition. The target vehicle VHF ranging system antenna pattern for this rendezvous configuration will be directed within the 0.53 degree solar disc for the first 10 minutes of initial acquisition and subsequent tracking. During this time interval the signal-to-noise ratio at the target vehicle ranging system receiver detector is at the minimum permissible level for adequate range tracking.

The complete VHF ranging system consists of the target vehicle ranging antenna and receiver-transmitter plus an antenna, transmitter-receiver and range processor on the manned vehicle. The transmitter-receiver and antenna on the target vehicle detects, synchronizes to and retransmits the ranging signal received from the manned vehicle.

During test and evaluation of the ranging system it has been determined that ranging interference may begin when interfering signals increase to within 5 db of the received signal (at either receiver). This interference disables synchronization and disrupts the ranging loop. If the probability is high that the ranging loop could be
disrupted by solar noise at the beginning of rendezvous, alternate rendezvous techniques can be developed.

To determine the possible amount of ranging interference, data provided in figures 3, 12 and 20 can be compared to the system parameters calculated for the planned mid-1973 rendezvous, and a probable amount and duration of interference found.

The signal strength, $P_r$, required at the input of the target vehicle receiver for the minimum permissible signal-to-noise ratio at the start of ranging is known to be $-134 \text{ dBw} \ (4 \times 10^{-14} \text{ watts})$. The transmitted signal from the manned vehicle will be at this value at the start of ranging, and for the subsequent 10 minute interval.

The target vehicle antenna design provides a 9 dB on-axis gain, resulting in the following effective antenna aperture, $A_e$:

$$A_e = \frac{G \lambda^2}{4} = \frac{(7.95)(1.15)^2}{(4)(3.14)} = 0.835 \text{ m}^2$$

where:

- $G = 7.95 \ \text{(9dB)}$ antenna gain
- $\lambda = 1.15 \ (259.7 \text{ MHz})$ received frequency wavelength

Received signal bandpass, $B$, is $7 \times 10^4 \text{ Hz}$. The signal power density, $D_r$, at the target vehicle antenna required to produce the minimum signal-to-noise ratio can be determined from $P_r$ by the equation:
A noise signal, $D$, 5db less than $6,800 \times 10^{-22} \text{W/m}^2 \cdot \text{Hz}^{-1}$, or $2,140 \times 10^{-22} \text{W/m}^2 \cdot \text{Hz}^{-1}$, could start disrupting the ranging loop. To determine the possibility of this happening, the predicted sunspot curve of figure 3 is entered at mid-1973, the time when rendezvous is expected. The predicted sunspot number at this time is seen to be about the same as that which occurred during early 1966. At the point where $D$ is $2,140 \times 10^{-22} \text{W/m}^2 \cdot \text{Hz}^{-1}$ on curve (C), figure 12, an estimated occurrence probability of about one burst per 1,000 hours is found. The chance of a noise burst with a power density above $2,140 \times 10^{-22} \text{W/m}^2 \cdot \text{Hz}^{-1}$ beginning during a 10 minute interval is then one in 6,000.

The probability of a disturbance due to a noise burst that begins before $t$, the start of the interval of interest or a
burst that begins after $t$, but before $t+10$ is given by:

$$P_{[Z/A]} = P_{[t-A < X < t+10]}$$

$$P_{[Z/A]} = \left[ \frac{10 + A}{60 \times 1000} \right] N$$

where:

- $N$ = bursts per 1000 hours
- $t$ = beginning time of interval
- $X$ = beginning time of the burst

The probability of a noise disturbance is then:

$$P_{[Z]} = E_A \left\{ P_{[Z/A]} \right\} = E_A \left\{ \frac{10 + A}{60,000} \right\} N = \frac{10 + E_A}{60,000} N$$

where:

- $E\{A\}$ = average burst duration,

$$E\{A\} = \frac{1}{\text{total number of bursts}} \sum \text{burst durations}$$

From figure 20, for 245 MHz, $E\{A\}$ is about 10 minutes.

Using this value for $P_{[Z]}$ calculations, $P_{[Z]} = \frac{10 + 10}{60 \times 1000} \times 1 = \frac{1}{3000} = .00033$. This low probability of occurrence is not sufficient to cause alternate rendezvous techniques to be developed.

B. Interplanetary Space Communication. The previous example illustrates a case where the probability of space communication interference caused by solar noise bursts is very low. Future uses of communication in deep space may require reception of low signal power densities during sunspot activity when the Zurich sunspot number is at 200 or higher. Suppose, for example, that an Earth to Mars communication link is required to operate when the planets are in superior conjunction.
(in line with each other and the sun, but on opposite sides of the sun), with the Zurich sunspot number at or above 200. If the signal power density required for proper operation at this distance is around $100 \times 10^{-22} \text{Wm}^{-2} \text{Hz}^{-1}$, solar noise bursts could exceed this level about 74 times per 1000 hours. This is found from the value given in figure 12, curve (a), doubled for a sunspot number of 200. The probability of a communication disruption in any 10 minute interval, based on an interference level of $100 \times 10^{-22} \text{Wm}^{-2} \text{Hz}^{-1}$, is 74 times greater than that found in the previous example, or:

$$P[Z] = \frac{10 + 10}{60 \times 1000} \times 74 = \frac{74}{3000} = .0246$$

This probability of interference may be significant enough to cause problems during the mission.

The three-month periodicity previously pointed out and shown in figure 19 can be used to predict noise activity on a short-term basis, and make allowances for the times when the burst activity is highest. If the short-term burst activity is recorded prior to activating the communication link, periods of maximum burst activity can be predicted. Mission activities can then be revised to minimize the effects of a possible disruptive outburst.
Sunspot and flare activity in the photosphere, chromosphere and corona regions of the sun are related phenomena. These activities produce random and highly variable radio noise interference levels, up to four orders of magnitude above quiescent background radiation. Sunspot activity can be predicted with good accuracy. Since sunspot activity and solar noise burst activity are related, a prediction of noise burst activity based on predicted sunspot number is feasible.

An analysis of burst data, recorded by radio astronomy for the latest sunspot minimum to maximum, provides a method for predicting the noise burst activity and the extent of possible communication disruptions.

When burst data are applied to future space communication system examples, the probability of communication interference is seen to be quite low, less than 1% for all but the highest levels of sunspot activity.
BIBLIOGRAPHY


Marion Francis Moen was born on October 30, 1935, in Indianola, Iowa. He received his primary and secondary education in Indianola, Iowa. He received his college education from the State University of Iowa, Iowa City, Iowa. He received a Bachelor of Science degree in Electrical Engineering from the State University of Iowa, Iowa City, Iowa in June, 1961.

He has been enrolled in the Graduate School of the University of Missouri-Rolla (St. Louis Graduate Extension Center) since 1965.