Calibrating the Signal Generator in the Sky

Amateurs have long used sun noise as a system-performance indicator on the VHF, UHF and microwave bands. Correlating sun noise to other factors can make this giant signal generator an even more useful crystal ball.

By Dr H. Paul Shuch, N6TX and Paul M. Wilson, W4HHK
Professor of Electronics
Pennsylvania College of Technology
One College Ave
Williamsport, PA 17701

PO Box 73
Collierville, TN 38027

The received amplitude of solar radiation, a standard indicator of performance for sensitive microwave receiving stations, is known to exhibit significant temporal fluctuations as a function of solar activity. Using sun noise collected at 2304 MHz at Paul (W4HHK) Wilson's station and daily solar activity indexes broadcast on WWV, we have used statistical methods to generate a model for predicting sun noise. Over a period of months, the model has proved accurate to within about half a decibel. We plan future studies to attempt to generalize the model for use at other stations and frequencies.

Sun Noise: Fact and Fallacy

Microwave experimenters have long calibrated the performance of radiotelescopes, satellite-tracking facilities and advanced Amateur Radio stations by measuring the intensity of emissions received from our nearest stellar neighbor, the sun. It's amusing, at technical conferences across the country, to hear boastful comparisons of system performance: "My EME station gets 15 dB of sun noise." "That's nothing; mine gets 17 dB!" Or perhaps an experimenter will use sun-noise measurements to justify a supposed design improvement: "I switched to Barry's feedhorn design, and my sun noise came up three quarters of a dB." In fact, unless the measurements were made at the same time, on the same day, at the same frequency, any conclusions drawn from such comparisons are specious.

The sun, like all stars, is a powerful fusion reactor. It is also a powerful generator of broadband electromagnetic radiation, much of which we see as sunlight, and some of which we hear in radio receivers as sun noise. The problem is, the sun is a poorly regulated signal generator. Daily and seasonal fluctuations in microwave radiation intensity of several decibels are the rule, not the exception.

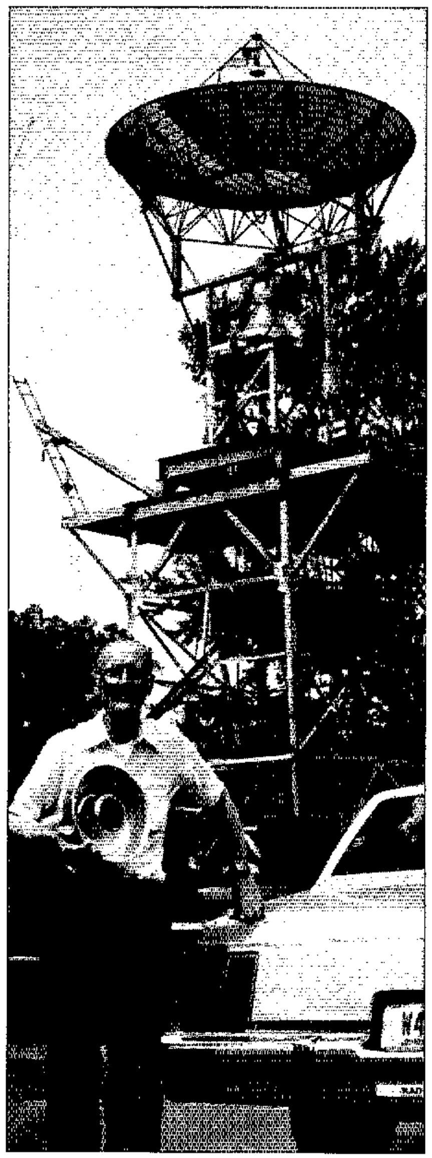

Fig 1—Paul Wilson, W4HHK, holds a 2304-MHz feed for his 17-foot Kennedy dish (background).

Fortunately, we need not leave these fluctuations unquantified. The US National Institute of Standards and Technology (formerly National Bureau of Standards) broadcasts over its standard frequency and time stations (WWV and WWVH) three daily indicators of solar activity: 10.7-cm solar flux, A index and K index. The exact meanings of these indexes may be known to astrophysicists, but not to us! And although the literature contains ample recent material dealing with the interpretation of WWV solar activity data,[1,2,3,4] we have adopted a more pragmatic approach to understanding solar noise: direct observation and statistical correlation.

Structuring the Experiment

The 2304-MHz station at W4HHK, involved in the first two-way EME contact on that band in 1970, is depicted in Fig 1. It consists of a 5.5-meter parabolic reflector with a 0.41 focal length-to-diameter (f/D) ratio on an azimuth-elevation mount. This system has been in regular operation since 1964. A circularly polarized 0.7-λ ID cylindrical waveguide feed horn with a choke ring yields a net antenna gain on the order of +39.5 dBic (decibels with respect to a circularly polarized isotropic source). An antenna-mounted GaAsFET preamplifier and low-loss feed line set the receiving system noise figure at 0.85 dB.

Since June of 1991, this station has been used to make daily measurements of sun noise by integrating audio noise in a 2.2-kHz receiver bandwidth from a linear CW detector, with AGC disabled. The antenna was pointed alternately at the sun and a cold point in the sky with an expected noise temperature of 25 Kelvins. The difference in received noise was then observed by averaging seven to ten readings on a digital rms voltmeter.

[1]Notes appear on page 44.

Several dozen such sun-noise measurements were made over a period of months so as to account for seasonal variations in solar activity. Concurrent with each observation, the 10.7-cm solar flux and mean geomagnetic field measurements (A and K indexes) were recorded from WWV. We hoped that these three solar activity indicators provided by NIST would serve as useful predictors of observed sun noise.

Statistical Analysis

W4HHK noticed some time ago, and reported at the 1991 Central States VHF Conference in Cedar Rapids, Iowa, a direct correlation between the WWV 10.7-cm solar flux and the sun noise he observed at 2.3 GHz. The WWV solar flux is based on sun noise received at local noon in Ottawa, Ontario, measured at a frequency of 2.8 GHz.[5] Since the frequencies of observation are reasonably close, the longitudes of the two observers are separated by less than one terrestrial time zone, and W4HHK's measurements were often made near midday, this correlation is not particularly surprising. As a first-order approximation, W4HHK hypothesized for his station the following relationship between sun noise and the WWV solar flux number:

$$\text{Sun Noise (dB)} = \sqrt{\text{WWV flux}} + 1 \quad \text{(Eq 1)}$$

This approximation, appealing in its simplicity, appeared to hold reasonably well for sun-noise measurements in the range of 15 to 16 dB, with errors increasing for higher and lower sun-noise levels. Fig 2 is a scatter diagram of the predictions from this model, as compared to measured sun noise, for a sample of three weeks' daily observations. Note the concentration of data points above the regression line for low values of sun noise, and below it for higher sun-noise values. Although a correlation coefficient of 0.916 was achieved, the obvious disparities between prediction and observation led us to believe that a better model could be built with additional independent variables (predictors), of which WWV gave us two candidates: the A and K indexes.

Adding the A and K Indexes to the Model

For this same preliminary sample, correlation was sought between the WWV solar flux index, A index and K index (*predictors*) and W4HHK's observed sun noise (the *response variable*). We expected the sun noise to follow the WWV flux index rather well, and it did, as seen in the scatter diagram of Fig 3A. As Fig 3B indicates, the relationship between A index and sun noise is not nearly as strong. And Fig 3C shows almost no correlation between sun noise and the K index. Thus, we conclude that the K index is the weakest predictor of sun noise, and exclude it from our further analysis.

Turning his attention to WWV 2.8-GHz solar flux and the A index, N6TX employed multiple linear regression analysis on a microcomputer to come up with the following refined predictive model from W4HHK's preliminary sample:

$$\text{Sun Noise (dB)} = 11.3 + (\text{WWV flux} \div 51) + (\text{A index} \div 141) \quad \text{(Eq 2)}$$

Agreement between observed and predicted values of sun noise, employing Eq 2, yielded only a negligible improvement (to 0.920) in correlation coefficient over the initial model. However, the resulting scatter diagram (Fig 4) shows that data points fall noticeably closer to the regression line than they did initially.

Satisfied that we had a working strategy, we next sought to refine our predictions by amassing a much larger data base of observations covering several months, and exploring various possible transformations of the regression model. One that gave us acceptable agreement between observation and prediction was:

$$\text{Sun Noise (dB)} = 12 + (\text{WWV flux} \div 59.5) + (\text{A index} \div 97.1) \quad \text{(Eq 3)}$$

which is merely a fine-tuning of Eq 2. Although further improvement in fit is doubtless possible, we submit this as our final model of the present study, and will explore its predictive validity below.

Testing the Predictive Model

Prior to generating the final predictive model, a holdout sample was randomly drawn without replacement from the sun noise and solar activity data base. Statistical tests were performed to assure that this sample constituted an unbiased representation of the underlying population. The size of the sample was tested to assure that it would produce statistically significant results. The pertinent WWV data were applied to Eq 3 to generate sun-noise predictions for the holdout sample, and these predicted values were compared to measured sun noise. They lined up well, as Fig 5 shows.

The resulting correlation coefficient of 0.927 represents a slight but noticeable improvement over Eq 2. It achieves significance well beyond the 0.05 level, which indicates excellent agreement between observation and prediction. Discrepancies we detected were random rather than systematic. That is, the correlation between the predictive errors and measured sun noise was insignificant (r = −0.37).

More importantly, the differences between prediction and observation averaged 0.17 dB, and never exceeded 0.44 dB, suggesting that our predictions are limited only by the inherent accuracy of the method we use to measure sun noise. We suggest that Eq 3 accurately predicts sun noise for the 2.3-GHz station at W4HHK, and will discuss a process for generalizing these results to other stations and frequencies.

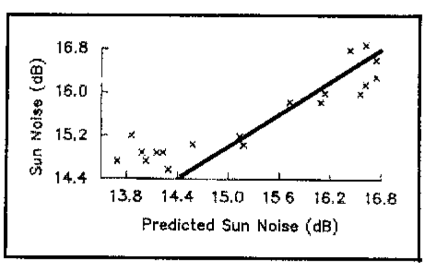

Fig 2—Scatter diagram of predicted versus observed sun noise, W4HHK model.

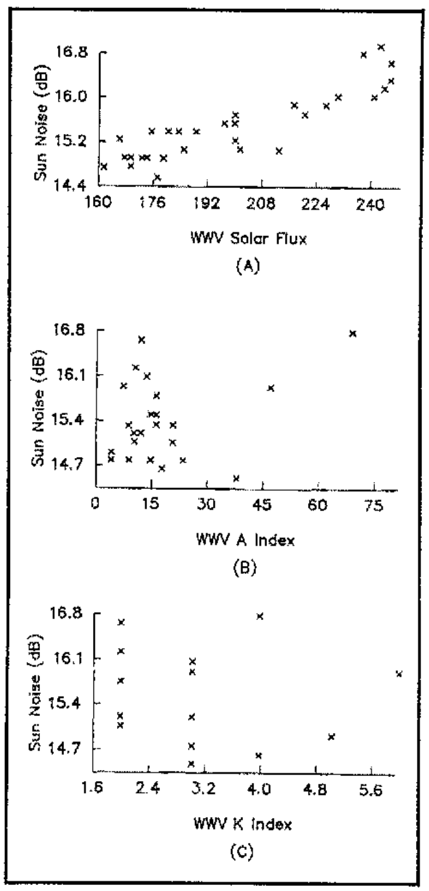

Fig 3—WWV solar flux (A), A index (B), and K index (C) as predictors of sun noise measured at W4HHK.

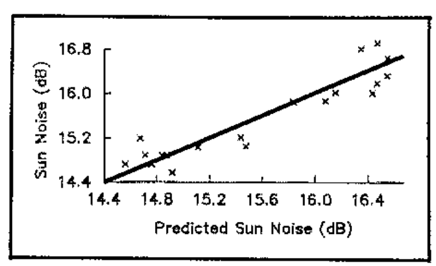

Fig 4—Scatter diagram of predicted versus observed sun noise at W4HHK, N6TX model 1.

The beauty of these results lies in the fact that, with sun-noise predictions accurate to within half a decibel, you can easily see what changes in your system noise temperature (and thus noise figure) are attributable to station improvements!

An Explanatory Hypothesis

The scientific method, as espoused at institutions of higher learning, requires that the investigator first formulate a hypothesis; design experiments to test that hypothesis; conduct those experiments to gather data; and perform statistical analysis to ascertain whether the data supports or rejects the hypothesis. We admit to having sidestepped established procedures somewhat, in that we first gathered data experimentally, then designed a statistical analysis procedure to sift through that data. We shall now totally subvert (and pervert) the scientific method, by utilizing that analysis to formulate a hypothesis!

Some call this the needle-in-a-haystack approach to science: "I don't know what I'm looking for, but I'm sure it's in there somewhere." Our most powerful analytical tool is the *interoccular trauma* test: "When a relationship is so overwhelming that it hits me between the eyes, I'll know I've found something significant."

What hit us between the eyes here is that the sun is supposed to be a thermal *black body*, radiating differently at different frequencies, as determined by its 5800-K surface temperature (see Fig 6, after Jespersen and Fitz-Randolph, 1990.) But microwave radiation from the quiet, or undisturbed sun (Fig 7), seems to fit a Planck radiation curve for a significantly warmer black body.[6]

Perhaps our receivers are responding not to the sun's surface temperature at all, but rather to its somewhat warmer (20,000 K) chromosphere, or even its amazingly hot (100,000 K) corona. Since, for example, solar flares are known to extend well into the sun's upper atmosphere, one could well expect the effective temperature *around* the sun to vary with solar activity—the very activity that the WWV data captures, and our statistics analyze.

Generalizing the Results

Note in Fig 7 that, at least over the range encompassing the amateur 902- through 5650-MHz bands, solar flux appears relatively linear with frequency. (Fig 7 is a log-log plot, so the region between 0.9 and 5.6 GHz will still appear as roughly a straight line on a linear graph). Such a line may be described in terms of its slope and y-intercept. In our general predictive model, solar flux will relate to the intercept, and slope can be expected to be indicative of geomagnetic activity.

If we accept the WWV solar flux and the A index as our predictors and observed sun noise as our criterion measure, then an appropriate model for sun noise at a particular frequency, measured by a particular station, will be of the general form:

$$\text{Sun Noise (dB)} = \alpha + \beta\,(\text{flux number}) + \delta\,(\text{A index}) \quad \text{(Eq 4)}$$

where α is a constant unique to the particular station (encompassing G/T and operating frequency), and β and δ weigh the contributions to measured sun noise of solar flux and geomagnetic activity, respectively. We have already estimated α, β and δ for the 2.3-GHz station at W4HHK. It now remains for us to determine such constants for other stations, at other frequencies.

Further Study

Thus far, all of our computations have been based upon sun-noise measurements taken by one station, at one frequency. A long term objective of our efforts, however, is to generate a predictive model of sun noise for *any* observer, given pertinent station parameters and WWV solar indexes. Toward this end, it will be necessary to accumulate a sizable data base of sun-noise observations from numerous stations operating in the various microwave bands. We believe that from such a data base, we can derive an equation that predicts sun noise for any station, given that station's antenna gain, system noise temperature, frequency of operation, and the pertinent WWV solar-activity data. The cooperation and assistance of the world's microwave radio amateurs is thus hereby solicited.

There are probably several hundred stations worldwide with EME, satellite and radioastronomy capabilities in the 420-MHz through 24-GHz Amateur Radio bands. We invite those capable of observing sun noise to participate in our research. Experimenters possessing such stations can make a significant contribution to knowledge by periodically measuring sun noise, along with the corresponding WWV A and K indexes and 10.7-cm flux readings. We ask that those desiring to participate in this research send logs of such readings monthly, along with as detailed a station description as they are able to supply, to N6TX at his byline address.

If we receive sufficient data, the statistical techniques outlined herein will be applied to the broader problem of developing a general sun-noise model. The results will be published in the Amateur Radio press and the scientific literature, and all participants will be gratefully acknowledged.

The present investigation is only a start. We look forward to including your data in this more ambitious study. If we hear from enough of you, you will most certainly hear more from us! Thanks in advance for your contribution to the radio art and science.

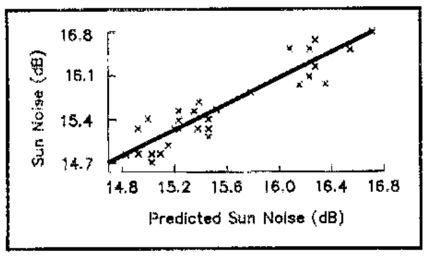

Fig 5—Scatter diagram of predicted versus observed sun noise at W4HHK, N6TX model 2.

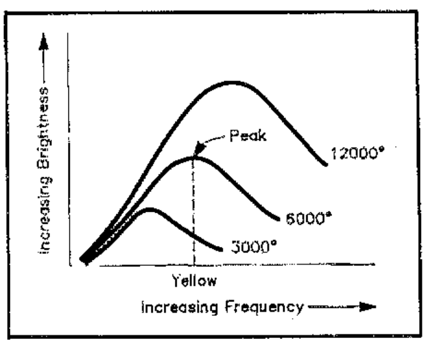

Fig 6—Heat signature varies with the temperature of the radiating body.[7]

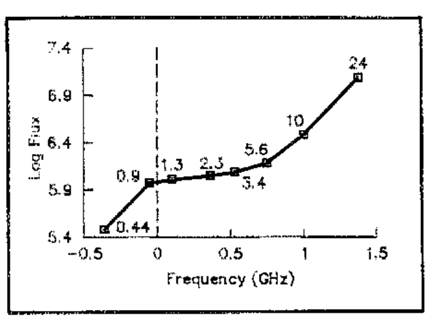

Fig 7—Microwave radiation from the sun seems to fit a far warmer black-body curve than we had expected the sun's temperature to produce. *(After Shaffer,* The ARRL UHF/Microwave Experimenter's Manual, *ARRL, 1990)*

Notes

[1] W. Atchison, "Calculating System Performance Using Solar Flux Data," *Proceedings of Microwave Update '91* (Newington: ARRL, 1991), pp 61-69.

[2] R. Healy, "Propagation Broadcasts and Forecasts Demystified," *QST*, Nov 1991, pp 20-24.

[3] E. Pocock and B. Blake, "Midrange Forecasts of Solar and Geomagnetic Activity," *QST*, Apr 1991, pp 22-27, 30.

[4] R. Beehler and M. Lombardi, *NIST Time and Frequency Services*, NIST Special Publication 432 (Boulder, CO: National Institute of Standards and Technology, June 1991).

[5] D. Rosenthal and J. Hirman, *A Radio Frequency User's Guide to the Space Environment Services Center Geophysical Alert Broadcasts*, NOAA Technical Memorandum ERL SEL-80, NOAA Space Environment Laboratory, Boulder, CO, Jun 1990. Note: Since June of 1991, WWV solar flux measurements have been made in Penticton, BC (49° N, 120° W).

[6] D. Shaffer, "Microwave System Calibration Using the Sun and Moon," *ARRL UHF/Microwave Experimenter's Manual* (Newington: ARRL, 1990), pp 60-64.

[7] J. Jespersen, and J. Fitz-Randolph, *Looking at the Invisible Universe* (New York: Atheneum, 1990).