TECHNICAL REPORT # 11

Date: August 1972
From: The Crawford Hill VHF Club, W2NFA
Subject: Use of, Solar Noise in EME System Evaluation

The limit of weak signal detection in an EKE system is determined by the effective gain of the antenna, Geff, and the system operating temperature, Tsys, as well as detection methods, signal modulation and scattering characteristics of the Moon. However, IF the mode of transmission is CW and the detection method is the human ear, then the limit is determined by Geff and Tsys. A measure of practical receiving system performance is the ratio of antenna gain to system temperature, Geff/Tsys.

A very simple and readily available method for measuring Geff/Tsys is by means of Sun noise. In fact it is inescapable that the ratio of Geff/Tsys is all that can readily be determined by Sun noise measurement alone. It is the purpose of this report to convince the EME enthusiast that indeed Geff/Tsys IS of more practical significance than knowledge of Geff or Tsys, separately, and to show how it may be measured and used in system evaluation.

While the engineering purist would like to know each system parameter, Geff., Tsys, feedline losses, etc., all of these factors are y lumped into the Sun noise measurement of Geff/Tsys' Any improvement in receiving system performance is related directly to this ratio regardless of whether it is a result of improved front end NF, higher antenna gain, lower feedline loss, corrected impedance match, etc. It is therefore evident that Sun noise measurement may be used for on-line adjustment of the receiving system. Any adjustment or system change which results in a greater Sun noise ratio will improve system performance. The receiving system may therefore be optimized without laboratory equipment and with the antenna in a physical attitude of practical interest in EME communications. Note the word optimized. It is NOT readily possible to determine which component is faulty if the system performance is below par. It is equally important to understand that there is interaction between antenna, feedline (if any used), connectors and receiver front end which may be of sufficient magnitude to demand that the system be optimized as a unit for peak performance. This last remark is especially important when the experimenter is faced with measuring tools of inadequate accuracy for determining such parameters as impedance match and small loss. And finally, Sun noise measurement may be used as a receiving system performance check once an optimum system has been achieved.

Theory

In this section derivation of the mathematical relations between Sun noise and practical systems for UHF will be presented. To begin with, the Sun at 1300 mc/s appears as a disc of nearly uniform brightness (temperature) equal in size to its optical disc subtending an angle of nearly 1/2 degree from the surface of the Earth. It is therefore not a 'true' point source radiator but may be considered as one for most practical size antennas at 1296 mc/s (i.e., antennas less than about 5 meters in diameter).

The radiation from the Sun is random in amplitude, phase and polarization and is smoothly distributed over any practical bandwidth. Randomly polarized means that receiver output noise will be the same in average amplitude regardless of orientation of 'a linearly polarized receiving antenna or sense of circularly polarized antenna aimed at the Sun.

Figure 1, presents the distribution of Solar noise radiation over a wide portion of the radio spectrum. The radiation is presented as a total flux density at the surface of the Earth, in watts per square meter of area per cycle of bandwidth and is for a "quiet" Sun. Typically the radiation will be higher in density than the curve.

In the United States a Solar flux density service is available at spot frequencies in the low microwave region. One of the spot frequencies is 1450 mc/s and several measurements are available per day. The data may be obtained by calling 303-635-8911 Extension 82-3377 and asking for the corrected Solar flux density at 1450 mc/s during the past 2h hours or at the period when your measurements were made. Since Solar noise does fluctuate it is advisable to have data available for a period of time before and after your home measurement in order to establish the flux at the time of your measurement.

An antenna with a physical area, A, in square meters and a single polarization, be it linear or circular, will intercept Solar noise power

$$P_{sun} = \frac{\Psi}{2} A \quad \text{watts/ cycle bandwidth}.$$

Where Ψ is the flux density given by Figure 1 (or NBS measured value) for a particular frequency, A is the physical aperture area and the factor 1/2 is necessary because only half of the total flux is accepted by a single polarization.

The actual power delivered to the antenna output terminals is always less than the power passing into the physical aperture by an antenna efficiency factor. The antenna efficiency is intimately related to the type of antenna, its design and construction. In general it is composed of a small amount of heat losses but mainly by the way in which the available antenna terminals are coupled to the aperture. A paraboloidal reflector with prime focus feed, for instance, has an efficiency which is due largely to the way in which the feed illuminates the reflector area and how much radiation is lost outside of the reflector area, called spillover, see Report #5.

The useful power available at the antenna terminals (port) can be written as:

$$P_{\substack{sun\\antenna}} = \frac{\Psi}{2} A \eta, \text{ where } \eta \text{ is the efficiency.}$$

In terms of effective antenna gain

$$G_{eff} = \frac{4\pi A \eta}{\lambda^2}.$$

$$P_{\substack{sun\\antenna}} = \frac{\Psi}{2} \frac{G_{eff} \lambda^2}{4\pi}$$

Since power is related to temperature through Boltzmann's constant, $k = 1.38 \times 10^{-23}$ watts/ cycle degree Kelvin,

$$kT_{\substack{sun\\ant}} = P_{\substack{sun\\ant}} = \frac{\Psi}{2} \frac{G_{eff} \lambda^2}{4\pi}$$

Thanks to W6YFK for this information.

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or

$$T_{\substack{sun\\ant}} = \frac{\Psi}{2} \frac{G_{eff} \lambda^2}{4\pi k} \qquad (1)$$

Equation (1) above gives the electrical temperature of the antenna at its output port due to radiation from the Sun ONLY (beam aimed at the Sun).

When the antenna is pointed away from the-Sun the output noise power drops to some low value which is determined by galactic noise and other noise received by the antenna.. Galactic noise at 1296 mc/s contributes typically lees than 20 K. The remaining noise received by the antenna is due to far side lobes directed towards the warm Earth. See Technical Report #5 for evaluation of these noise contributions for a paraboloidal reflector antenna system.

Finally when a receiver is connected to the antenna port, an additional noise temperature appears due to the

receiver. Since all of these noise temperatures represent uncorrelated noise power, they may be summed arithmetically, referenced at the antenna port for convenience.

The sum of receiver noise plus antenna noise when the beam is pointed away from t he Sun is called system noise and characterized by a system temperature, T_{sys}. (See Technical Report #3) When the antenna with receiver connected is pointed at the Sun, the additional Solar noise produces a total noise temperature at the antenna port Tsys + sun-ant* The ratio of noise temperature to “ON” to “OFF” the Sun will be

$$\frac{T_{sys} + T_{sun-ant}}{T_{sys}} = R \qquad (2)$$

Since the receiving system *is* the same for "ON" and "OFF" the Sun (we assume here that the receiver is linear in amplitude response, and is used in its widest bandwidth to accept as much noise as possible), the ratio R may be measured directly at the receiving system output. This may be done with *a* suitable base band power meter or voltmeter. Most VOM’s have an a-c voltage range low enough to measure receiver output noise and a decibel calibrated scale to simplify the reading of R directly in decibels.

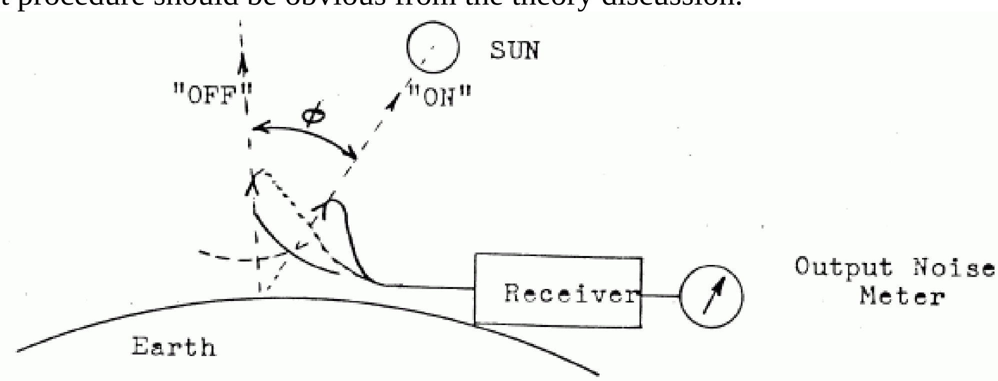
Substituting equation (1) into equation (2) and solving for the ratio Geff/T_{sys} gives.

$$\frac{G_{eff}}{T_{sys}} = \left(\frac{4\pi}{\frac{\psi}{2k}\lambda^2}\right)(R - 1) \qquad (3)$$

The first term *is* a constant for a given wavelength and Solar flux while the second term is the measured value of output noise ratio "ON" to "OFF" the Sun in real numbers, not decibels, minus one. Thus the value of G_{eff}/T_{sys} has been determined within the accuracy of the Solar flux at the time of measurement.

Sun Noise Measurement

The measurement procedure should be obvious from the theory discussion.



However, some details should be elaborated on with the aid of the above drawing.

1. The Sun position should be high in elevation to avoid ground reflections.
2. The angle Ø of pointing "OFF" the Sun should be several beam widths or until no further decrease in noise is observed. Remember that the Earth is rotating so that the position of the Sun is constantly changing at a rate of approximately 15 degrees per hour.

3. Point the beam accurately at the Sun by maximizing the receiver output noise.

4. A damped noise meter will be more accurate but require more care in antenna pointing.

5. The output noise meter must be calibrated in voltage, current, power or directly in decibels. The relations between these quantities are:

$$\text{Ratio in Decibels} = 20 \log_{10} \frac{V_1}{V_2} = 20 \log_{10} \frac{I_1}{I_2} = 10 \log_{10} \frac{P_1}{P_2}$$

Slide rule accuracy is sufficient in converting decibels to real ratios. Those unfamiliar with the use of the decibel scale are urged to consult the ARRL Handbook or other similar references.

6. Operate the receiver with AVC "OFF", BFO "ON", and just sufficient gain to obtain a readable level on the output meter when pointed "OFF" the Sun. Front end noise MUST predominate the system.
7. Most VOMs have 2000 ohms/volt impedance on a-c scales. Do not measure at a low-Z output but use a transformer to match impedances approximately. This avoids overload (compression) problems caused by increasing the receiver gain to obtain sufficient meter deflection. Use a VTVM on the lowest stable a-c scale if possible.
8. A receiving system non-linearity (compression) check should be made if possible. However, in view of the limited Sun noise ratio expected with most reasonable size antennas, compression should not ordinarily be a problem.
9. Take several measurements for confidence.

It is beyond the scope of this report to analyze all receiver systems. It is therefore the burden of the experimenter to determine whether (8) above requires consideration. It is quite possible in more elaborate double and triple conversion receivers to have gain levels and noise figures of succeeding stages poorly proportioned so that system performance does not meet measurement requirements. A linear dynamic range of at least 20 db is required for accurate Sun noise measurements where the measured Solar noise ratio, R, does not exceed about 14 db.

Example and Results

To bring into focus the preceding discussion a useful example will b e shown here.

Assume an antenna of the type described in Technical, Report #5 and a receiving system with low noise front end design of the type described in Technical Report #8. Then assume that a measurement of Solar noise ratio ("ON" to "OFF" the Sun) is made when the Solar flux is known to be 80 x 10^{-22} wts/m^2- cycle. The measured value of R was found to be 7.95 (+9 db).

Using equation (3) and appropriate constant values for 1296 mc/s

$$\frac{G_{eff.}}{T_{sys}} = \left(\frac{4 \times 3.1416}{\frac{80\times10^{-22}}{2\times1.38 \times 10^{-23}} \times (0.23)^2}\right) \times (7.95-1)$$

Carrying out the arithemetic gives

$$\frac{G_{eff}}{T_{sys}} = (0.82) \times (6.95) = 5.7 \quad \text{or } (+7.56 \text{ db})$$

The expected values of antenna gain and receiver system temperature are approximately 3160 (+35db) and 400°K respectively. The expected value for

$$\frac{G_{eff}}{T_{sys}} = \frac{3160}{400} = 7.9 \quad \text{or } (+8.89 \text{ db})$$

The discrepancy of 1.42 db in the receiving system can only be accounted for by either low antenna gain or higher system noise or a combination of both. The assignment of this discrepancy requires further measurement, to be discussed in the next section. Without further correction adjustments or improvements to the receiving system the receiving system will simply suffer by 1.42 db from expected results, a not too serious discrepancy.

How now does the value of $G_{eff}/T_{,vs}$ relate to receiving moon bounce signals?. To answer this question let us assume another example of interest. Assume that W2NFA is transmitting on 1296 mc/s with an antenna gain of 45 db (G_t = 31600) and effective power into the feed of P_t = 200 watts (+53 dbm). The signal-to-noise ratio at your receiver output will be:

$$\frac{S}{N} = \frac{P_t\ G_t\ L\ G_r}{k\ T_{sys}\ B}.$$

Where the average path loss, L, between isotropic (Gain = 1) antennas for the complete EME path is -271 db at 1296 mc/s. G_r is your antenna, k is Boltzmann's constant, 1.38x10-20 milliwatts/cycle-°K (-198.6 db) and B the receiving system bandwidth will be assumed to be 100 cycles (B = +20db). Note the occurrence of the ratio G_r/T_{sys} in the S/N formula. The same formula expressed in decibels wit the ratio G /T as a single term is:

$$\frac{S}{N}_{db} = P_t + G_t + L - k - B + (G_r/T_{sys}) \quad \text{all expressed in decibels}$$

$$\cancel{= +53 +45} -271 +198.6 -20 +10.86$$

$$= +16.46 \text{ db} \quad \text{a substantial EME signal ! ! !}$$

It would be useful and interesting to ask what minimum value of Sun noise ratio is required in order to hear W2NFA at all? Based on the ear bandwidth threshold S/N of unity in a 100 cycle band, the formulas give

$$\frac{Geff}{Tsys} = 0.273 \ (-5.6 \text{ db}) \qquad \text{and } R = 1.33 \ (+1.2 \text{ db})$$

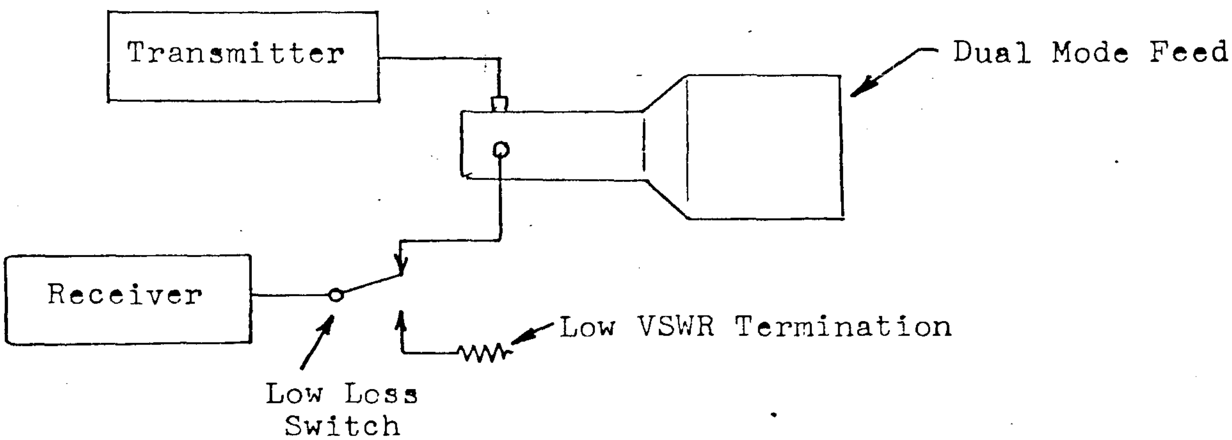
A more reliably detected S/N would be for

$$\frac{G_{eff}}{Tsys} = -1 \ (o \text{ db}) \qquad \text{which requires a Sun noise 11 = 2.2 } (^{+}3.4 \text{ d}$$

Keep in mind that these calculations are influenced by the intensity of Solar radiation at the time of measurement. This variation however is usually of the order of 1%(.05db) and is not serious. Solar flares do occur and can disturb the flux density at 1296 mc/s by a much greater percentage.

Estimate of Receiver Temperature

In a practical working transmit-receive system it will be necessary to protect the receiver front end with a high isolation relay in the schematic manner shown below.



The protection relay can be a transfer relay switching the receiver front end between the antenna and a low VSWR termination at ambient temperature. Although the normal use of the relay is in the T-R mode, by operating it independently with the receiver operating only, the relay can be used to alternately connect the receiver to noise generators at ambient and antenna temperatures. This scheme is effectively a "hot"-"Cold" load method of determining receiver front end temperature (noise figure).

The procedure is to measure carefully the change in receiver output noise when the termination and then the antenna are connected to the receiver. The relationship between these factors is:

$$M = \frac{T_{rcvr} + T_o}{T_{rcvr} + T_{ant}}$$ all Ts are in degrees Kelvin.

From this formula the expression for T_{rcvr} may be derived.

$$T_{rcvr} = \frac{T_o - M\ T_{ant}}{M-1} \qquad (4)$$

The termination temperature, T_o may be determined by direct measurement with a thermometer. In general if the termination is in an ambient environment then ambient temperature may be used.

$$T_o \text{ in } ^oK = T_{amb} \text{ in } ^oC + 273^o$$

The antenna Temperature can not be exactly determined: however if the antenna system is narrow beam with low side lobes (small spillover) the antenna temperature should be in the range 30 to 70°K.

If the antenna system is of the type described in Tech. Report #5 the estimated noise temperature may be as high as 85°K. See Report #5 for assignment of noise sources.

After measuring the noise ratio, M, it is a simple calculation to determine the limits of T_{rcvr}.*

Example: Assume a measured value of M = 1.6 (2.0 db) and ambient temperature of 27 °C, the calculations proceed as follows:

$$\text{if } T_{ant} = 30^{o}K, \quad T_{rcvr} = \frac{300 - 1.6x30}{1.6-1} = 420^{o}K$$

$$\text{if } T_{ant} = 70^{o}K, \quad T_{rcvr} = \frac{300 - 1.6x70}{1.6-1} = 312^{o}K$$

This gives an error of ±15% in receiver temperature. While this sort of accuracy may not be impressive, the method represents a practical means by which an experimenter may obtain a reasonable estimate of his receiver performance. It should be pointed out also that the _
error in measuring Trcvr with commercial noise generators is of the order ±0.5 db unless calibration facilities are available. (±10%)
If a section of lossy feedline must be inserted between antenna port and receiver front end, then the Trcvr obtained by this procedure should be corrected by the method in Technical Report #3. However, if the lossy feedline is part of the operating system then the correction may be academic.

A not too insignificant feature of this method of measuring is that it can be used frequently to check system performance without disturbing the operating system.
A simple error analysis shows that the percentage error in the determination of T rcvr, increases as T rcvr decreases. The accuracy may be improved by improving (i.e. lowering) T_{ant*}
This may be accomplished in part by using the high efficiency dual-mode feed described in Report #9 alone.

The procedure of measurement is the same with the following reservations.

1. The feed should be aimed directly at the zenith with as little surrounding obstacles in view. An elevated location would be desirable to avoid any obstacles such as buildings, trees and natural surface contours.
2. The receiver, switching relay and antenna should be connected together with virtually no feedline between.
3. Under these conditions Tant should be in the range 20 to 30° K

It may be of some interest to note here that the background temperature of the universe at 1296 mc/s does not exceed about 5° K. However, since any practical antenna has some inherent heat loss (I^2 R) and has a radiation pattern that intercepts some Earth temperature radiation, this minimum background temperature is very difficult to achieve. In the case of the dual mode feed, its radiation pattern even though well controlled has far side lobe levels which when 0 integrated ove5 the region of the Earth will contribute 10 to 15 K .

In addition, I^2 R heat loss in the feed itself can contribute as much as the universe temperature. Consider that 0.1 db of insertion loss at 290 °K will introduce about 7°K to the antenna temperature.
A very wide beam antenna such as a feed when pointed at the zenith even in the presence of Solar radiation will still receive the minimum universe background temperature even though the Sun is at a very high temperature it is an insignificant portion of the universe or even that portion of the universefseenl by the wide beam feed antenna.

Remarks

A method of system performance evaluation has been described employing Solar radiation at 1296 mc/s and a method of estimating receiving system temperature has been suggested. Both methods use a minimum of laboratory equipment and may be easily performed by an interested experimenter.

For those who may be interested, the Moon flux density is approximately 600 times less than the Sun at 1296 mc/s and so will be very difficult to observe with even a reasonable G/T ratio.

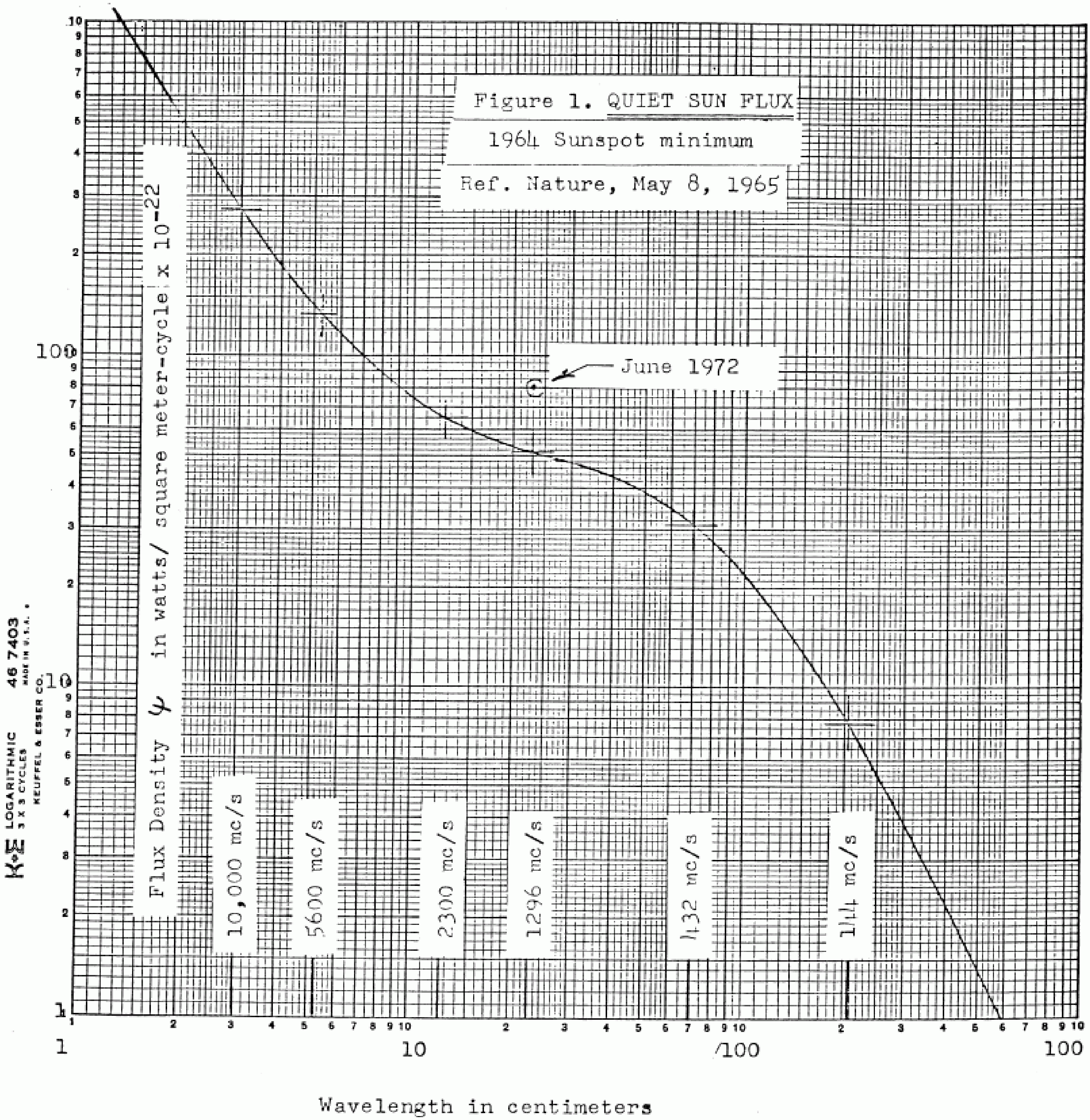


Figure 1. QUIET SUN FLUX
1964 Sunspot minimum
Ref. Nature, May 8, 1965
June 1972
Flux Density ψ in watts/ square meter-cycle x 10-22
10,000 mc/s
5600 mc/s
2300 mc/s
1296 mc/s
432 mc/s
144 mc/s
1
10
100
Wavelength in centimeters
K+E LOGARITHMIC 3 X 3 CYCLES KEUFFEL & ESSER CO. 46 7403 MADE IN U.S.A.