AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
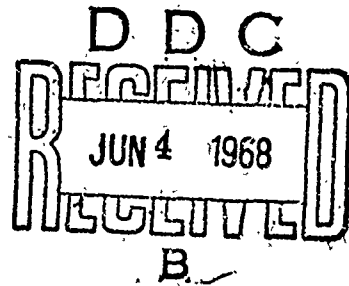
L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS 01730

A Proposed Index for Measuring
Ionospheric Scintillation

HERBERT E. WHITNEY
CHESTER MALIK

D D C

RECEIVED

JUN 4 1968

B

OFFICE OF AEROSPACE RESEARCH
United States Air Force

AD 669805

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

A Proposed Index for Measuring Ionospheric Scintillation

HERBERT E. WHITNEY
CHESTER MALIK

OFFICE OF AEROSPACE RESEARCH

United States Air Force

Abstract

Signals from radio star sources and satellites are regularly used for study-ing ionospheric irregularities. Amplitude and phase deviations can be imposed on the signals from these sources as they traverse the ionosphere. A parameter frequently used to describe the magnitude of this scintillation effect is scintilla-tion index.

An experiment was designed to correlate various methods of making scintil-lation measurements; observations were made at 40 MHz using the ionospheric beacon, S-66. It is shown that when the law of the receiver detector is known, a conversion method allows comparison of data and statistics on scintillation index.

A simplified method of scaling scintillation index is described. The accu-racy of the simplified method is determined by a comparison with measurements of scintillation index by machine computation.

Contents

Illustrations

Table

A Proposed Index for Measuring Ionospheric Scintillations

1. INTRODUCTION

Studying the effects of ionospheric irregularities often involves measuring the amplitude and phase variations imposed on a signal as it traverses the iono- sphere. Many workers have used signals from radio stars and satellites to record the changes in amplitude known as scintillations. Several measures are used to characterize the depth of scintillations; each of these measures is called a "scintillation index" (S. I.).

One measure is to use a scale from 0 to 5 and by visual inspection, without actual measurement, assign a value to the record. Other ways involve scaling the deviation of the signal amplitude from the mean amplitude. Four measures are thus possible, depending on whether mean deviation or root-mean-square deviation is used and whether the record is proportional to voltage or power. If the probability distribution of the amplitude deviation is known, it is possible to relate the four measures of scintillation index (Briggs and Parkin, 1963). While it is difficult to relate these measures theoretically because the probability dis- tribution of the amplitude deviation is not in general known, experimental compar- isons show that they are proportional to each other. These relationships and additional considerations are given in the cited reference.

2

However, in most cases, only a relative measure of scintillation index is required. For a statistical analysis that involves a long period of time, such as a study of the seasonal dependence of scintillations, it is important that a standard method of data scaling be used. The notation that has been adopted by AFCRL and the JSSG (Joint Satellite Studies Group) is:

$$\text{Scintillation Index} = \frac{P_{max} - P_{min}}{P_{max} + P_{min}}$$

where P_{max} is the power amplitude of the third peak down from the maximum excursion of the scintillations, and P_{min} is the power amplitude of the third level up from the minimum excursion. The use of this expression is demonstrated in Figure 1. The chart record is calibrated in dBm which is converted to relative power levels for calculation of S.I. Over the period 1730 to 1745 E.S.T. an index of 40 percent is obtained.
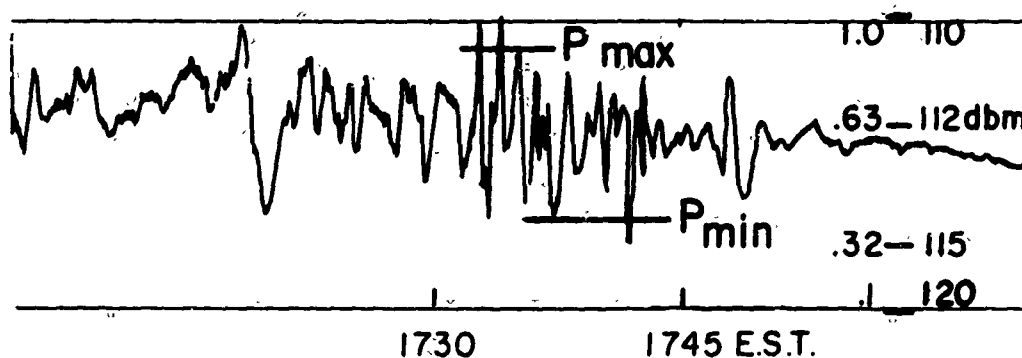
Figure 1. 136 MHz Scintillations from the Early Bird Synchronous Satellite
S.I. $= \frac{P_{max} - P_{min}}{P_{max} + P_{min}} = 40\%$

However, even though only relative values are usually required in a study of ionospheric scintillations, problems do arise in the comparison of data taken by various workers. Some measures of S.I. may have been scaled from chart divisions rather than by using an accurate calibration. The S.I. scaled from the chart divisions under an assumption that the chart display is either linear in power or voltage can lead to errors; in reality the chart amplitude could be somewhere in

between, because it depends on the law of the receiver detector. Also, statistics on satellite scintillations may be in the form of a voltage-index distribution based on a voltage calibration.

For comparison of data, it is useful to have a conversion-relationship between power index, S.I. $_{(p)}$, and voltage index, S.I. $_{(v)}$. If data was obtained from a receiver with AGC and the slope of the detector curve is known, scintillation index values based on chart divisions can be converted for comparison on a S.I. $_{(p)}$ basis.

Because of the emphasis on relating statistics on ionospheric scintillations to the problems of communication engineers, the following method was developed for converting data to a common base, S.I. $_{(p)}$. The amount that a signal fades is important to communication engineers and is related to scintillation index by the following:

$$\text{Signal fades (dB)} = 10 \log \left[1 - \text{S.I.}_{(p)} \right] = 20 \log \left[1 - \text{S.I.}_{(v)} \right].$$

For example, if S.I. $_{(p)}$ = 0.5 = 50 percent, then the signal fade is 3 dB.

Since the signal fade in dB would be the same on either a linear power or linear voltage display, the relationship is formed: S.I. $_{(p)}$ = 2 S.I. $_{(v)}$ - S.I. $_{(v)}^2$.

This conversion method can be extended to cover receivers that are not linear with input power or voltage, such as a receiver with AGC, but do have a constant slope to the detector curve over the fading range, by the following:

$$\text{S.I.}_{(p)} = 1 - \left[1 - \text{S.I.}_{(x)} \right]^x$$

where S.I. $_{(x)}$ is the scintillation index measured in chart divisions with a receiver that has a detector law exponent of x.

2. EXPERIMENTAL RESULTS

To determine the accuracy of the described method for converting S.I. values to a common base, the following experiment was made. Three R-390 Collins receivers were gain adjusted so that a 40 MHz satellite signal received on a common antenna and a common frequency converter, whose output had been equally divided into three parts, would detect the identical signal in three different modes: linear power mode, linear voltage mode, and the AGC mode. As shown in

4

Figure 2, the detector characteristics of each receiver had been carefully measured to determine over what signal range the receivers would be essentially linear with power or voltage or maintain a constant detector law.
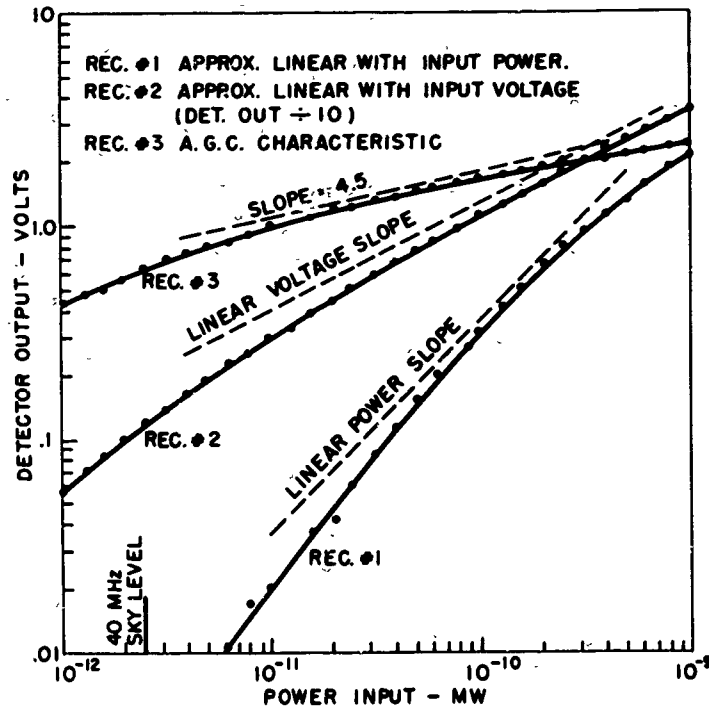
Figure 2. Detector Characteristic of 3 R-390 Receivers

By careful adjustment of the receiver gains and the chart recorder gains to maintain a full-scale deflection for the same input level, it was possible to simultaneously record identical signal excursions in the three modes. Each channel was accurately calibrated so that scintillation index could be measured for the three modes for identical signal excursions either using chart-division scaling or the voltage and power calibration. A sample chart record is shown in Figure 3. For this analysis identical signal peaks were used for the calculations of S.I.

Figure 3. Illustration of Scaling of Scintillation Index for Three Detector Characteristics

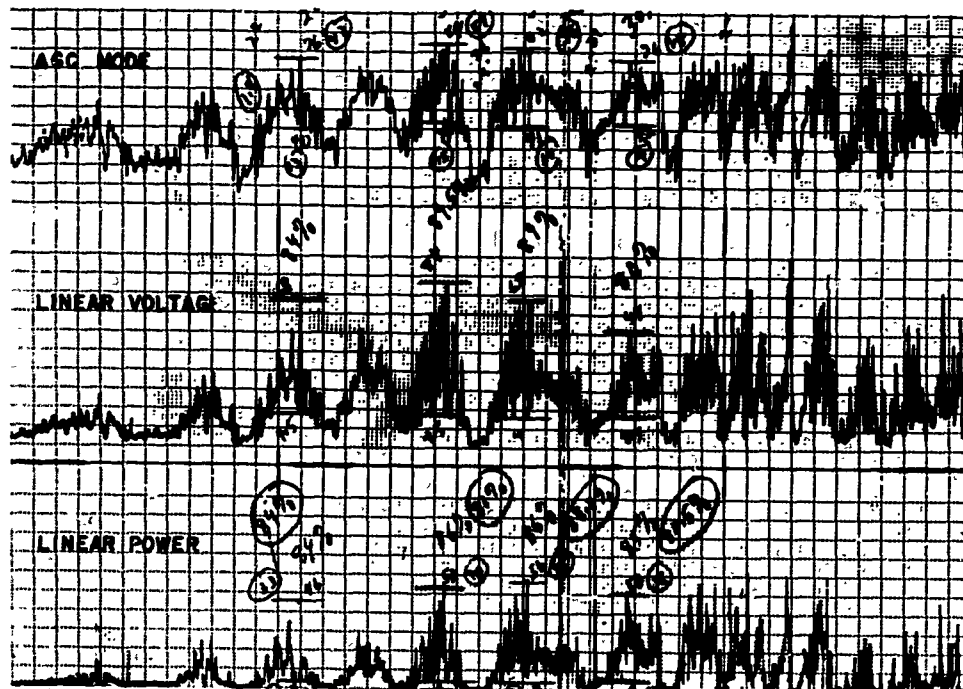Scintillation index was calculated for various degrees of scintillation for all three modes. These index numbers were then plotted against each other in various ways to determine the practicability and relative statistical accuracy of comparing (1) results of equipment having dissimilar characteristics, (2) scintillation measurements derived when calibrations were not taken and a detector characteristic law was assumed, and (3) conversion of scintillation measurements to a common standard.

The results of the experiment to compare scintillation index measurement are shown in Figures 4 through 8. Figure 4 shows the plot of the index obtained by using the signal power calibration for the linear voltage receiver (middle channel of Figure 3) vs. the index for the linear power receiver (lower channel). If perfect accuracy was obtained in the calibration and scaling, each channel would indicate the same S. I.; however, there is a mean error for the plotted points of about ± 2.2 percent.
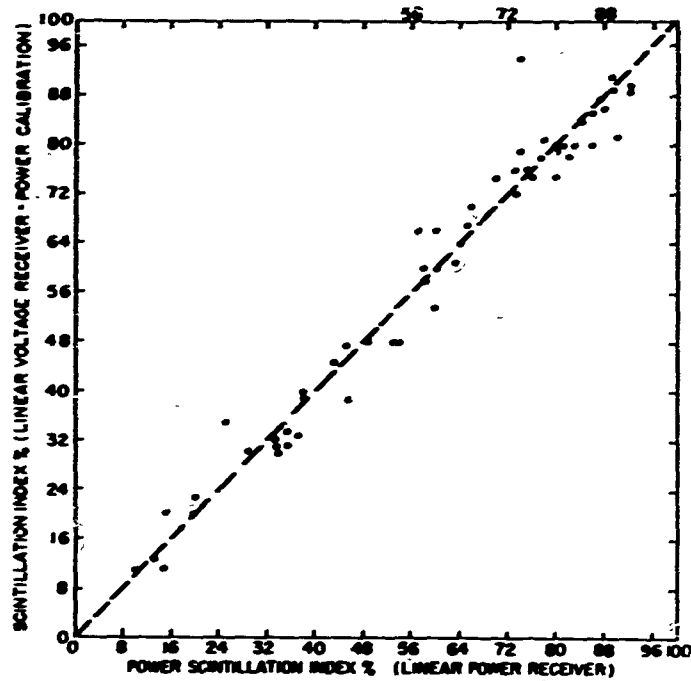
Figure 4. Measured Values of Scintillation Index from
Linear Voltage Receiver vs. Measured Values of Scintil-
lation Index from Linear Power Receiver. Power cali-
bration for both receivers

Figure 5 shows the plot of the index obtained by using the signal power cali-
bration for the AGC receiver (upper channel of Figure 3) vs. the index for the
linear power receiver. There is a mean error for the plotted points of $\pm$ 4 per-
cent.

Figure 6 shows the plot of the index obtained by using the signal voltage
calibration for the linear voltage receiver vs. the index for the linear power
receiver. The solid curve represents the relationship $S.I._{(p)} = 2 S.I._{(v)} - S.I._{(v)}^{2}$.
The scatter in the points shows a mean dispersion of about 4 percent.

Figure 7 represents the same data as Figure 6, but in this case the voltage
index was scaled using chart divisions.

Figure 8 shows the plot of index values taken from the AGC channel using
chart divisions. The solid curve represents the relationship $S.I._{(p)} = 1 - (1-S.I._{(AGC)})^{4.5}$. The exponent of 4.5 represents the mean slope of the AGC
detector characteristic as shown in Figure 2.

Figure 5. Measured Values of Scintillation Index from Receiver with AGC Characteristic vs. Measured Values of Scintillation Index from Linear Power Receiver. Power calibration for both receivers

$$SI_{(P)} = 2 SI_{(V)} - SI^2_{(V)}$$

Figure 6. Measured Values of Scintillation Index from Linear Voltage Receiver vs. Measured Values of Scintillation Index from Linear Power Receiver. Voltage calibration for linear voltage receiver. Power calibration for linear power receiver

8

Figure 7. Measured Values of Scintillation Index from Linear Voltage Receiver vs. Measured Values of Scintillation Index from Linear Power Receiver. Chart division calibration for linear voltage receiver. Power calibration for linear power receiver
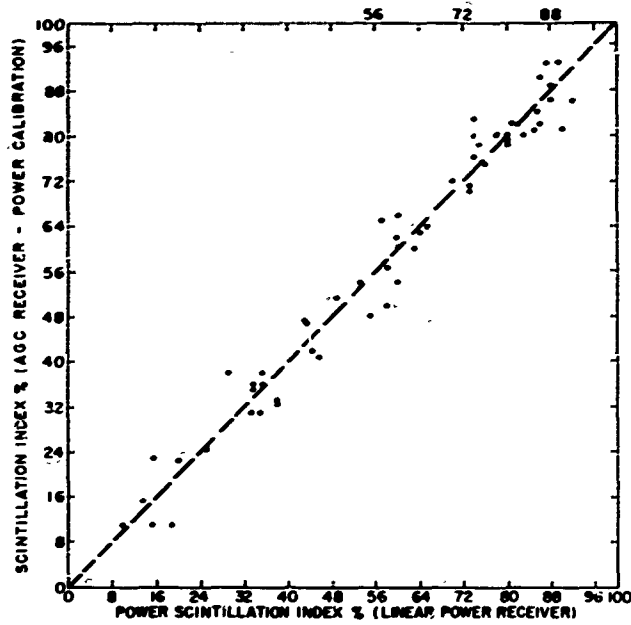

Figure 8. Measured Values of Scintillation Index from Receiver with AGC Characteristic vs. Measured Values of Scintillation Index from Linear Power Receiver. Chart division calibration for AGC receiver. Power calibration for linear power receiver
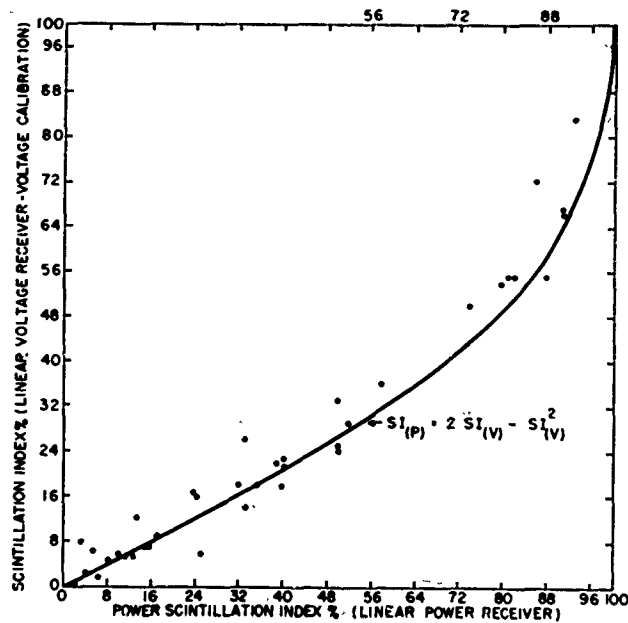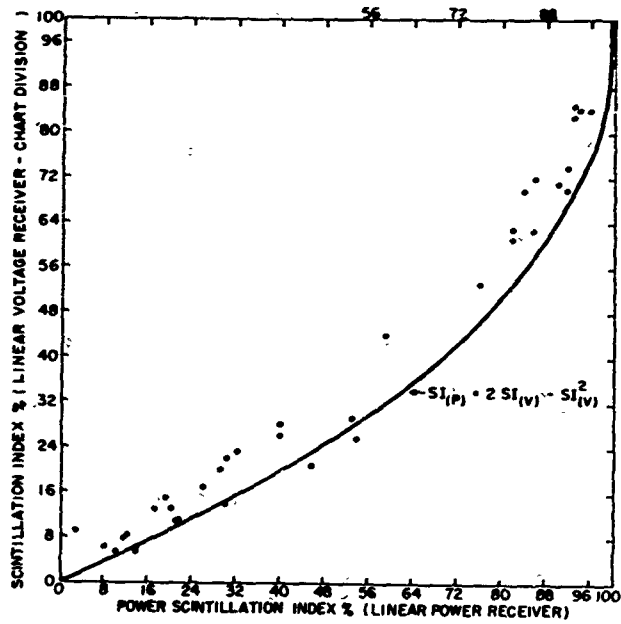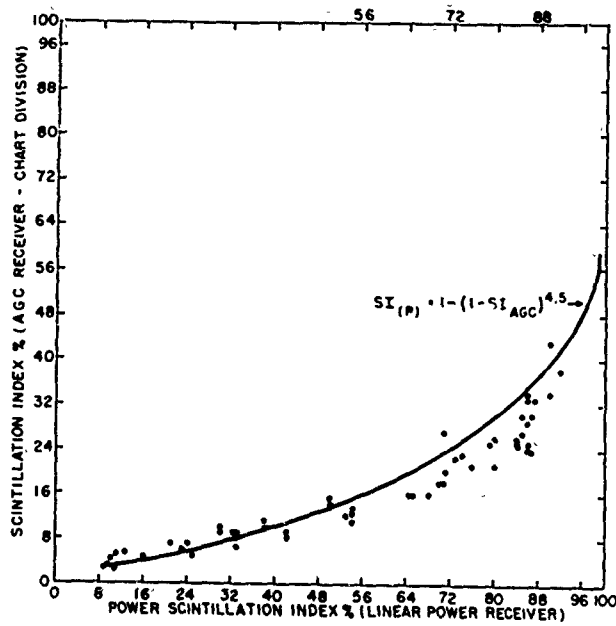
3. SCALING OF SCINTILLATION INDEX

It was pointed out in a preceding section that scintillation index was defined as $\frac{P_{max} - P_{min}}{P_{max} + P_{min}}$. At first the measure of S.I. was made by measuring the two levels and then computing, either by machine or by hand, the resulting S.I.

The first step was to mark the P_{max} and P_{min} levels on the chart for each time period that S.I. was to be read. P_{max} was arbitrarily chosen as the third peak down from the maximum and P_{min} as the third minimum up from the deepest fade. In the case of the low altitude satellite, S.I. was read either at the peak of the Faraday cycle or once per minute if Faraday periods were obscured by heavy scintillation. For the synchronous satellite signals, scintillation index was measured in each 5 minute interval. The time constant of the recording system was chosen to be short compared with the fastest scintillation.

The second step was to read P_{max} and P_{min} as a relative power level based on an accurate amplitude calibration of the chart deflection. If the calibration had been made in decibel steps, it was converted to an appropriate numerical ratio. Scintillation index was either computed manually, using the formula, or P_{max} and P_{min} were punched on cards for machine calculation of S.I. and further analysis.

A simplified method of measuring S.I. has evolved which is now implemented for all S.I. measurements. It again depends on an accurate amplitude calibration in decibel steps of the chart deflection. P_{max} and P_{min} are determined in the same manner as described in step 1 above. The decibel change of $P_{max} - P_{min}$ is then read, using the receiver amplitude calibration curve. The measured values in decibels of $P_{max} - P_{min}$ are then converted to S.I., using the curve shown in Figure 9. If further analysis is required, then either the decibel values of $P_{max} - P_{min}$ or the values converted to scintillation index can be punched on cards for machine processing.

The conversion graph shown in Figure 9 was determined by assuming equal percentage changes from the average level for P_{max} and P_{min}, changing those values to a decibel change and then summing them for the total decibel change as shown in Table 1. For example, based on an arbitrary average level of 1.0, a S.I. = 50 percent corresponds to a P_{min} = 0.5 = 3 dB, a P_{max} = 1.5 = 1.77 dB, and, therefore, a total change for $P_{max} - P_{min}$ of 4.77 dB.

As a check on the accuracy of the simplified method compared with the previously used method of machine computation, several values of scintillation index were measured using both procedures. The calibration of an S-66 record at 41 MHz was chosen because the average level for low altitude satellites changes over a far greater range than that from synchronous satellites.
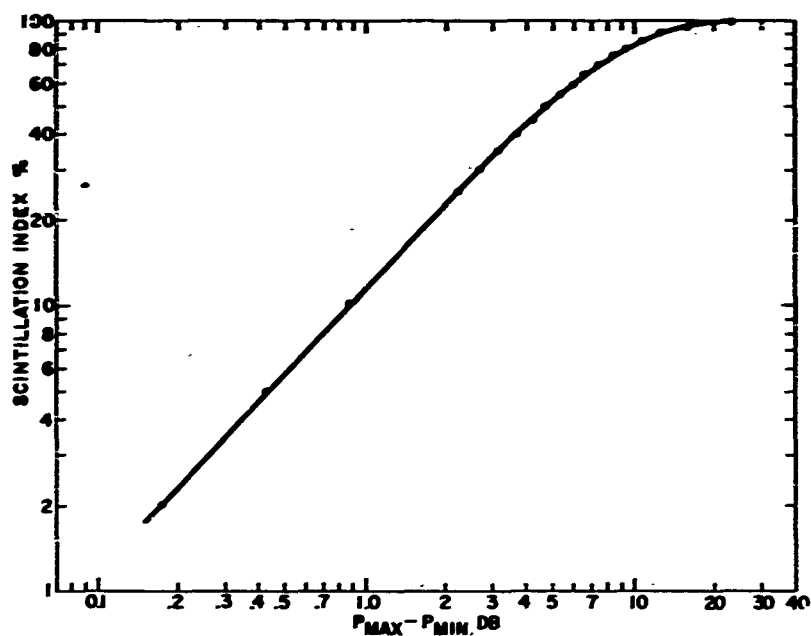
Figure 9. Graph for the Conversion of P_{max} - P_{min} to Scintillation Index.
P_{max} - P_{min} is the peak-to-peak excursion of a scintillating signal and is measured in decibels based on an amplitude calibration of the chart record

Table 1. Conversion Table: P_{max} - P_{min}(dB) vs. S.I. (%)

-dB	+dB	P_{max} - P_{min}(dB)	S.I. (%)
.09	.09	.18	2
.22	.21	.43	5
.46	.41	.87	10
.71	.61	1.32	15
.97	.79	1.76	20
1.25	.97	2.22	25
1.55	1.14	2.69	30
1.87	1.30	3.17	35
2.22	1.46	3.68	40
2.60	1.61	4.21	45
3.01	1.76	4.77	50
3.47	1.90	5.37	55
3.98	2.01	5.99	60
4.56	2.18	6.74	65
5.23	2.31	7.54	70
6.02	2.43	8.45	75
6.99	2.55	9.54	80
8.24	2.67	10.91	85
10.00	2.79	12.79	90
13.00	2.90	15.90	95
20.00	2.99	22.99	99
30.00	3.00	33.00	99.9

The results of this comparison are shown in Figures 10, 11, and 12. The measurements of $P_{max} - P_{min}$ in dB and their conversions to S. I. are plotted against the normal method of machine computation of S. I. Figure 10 corresponds to the case of measuring S. I. for weak signals, that is, where the average level is about 1/4 of the chart width, Figure 11 for average levels of about 1/2 of the chart width, and Figure 12 for strong signals with an average level about 3/4 of the chart width. The deviations of the points from the dotted line show the lack of perfect agreement between the two methods of measurement. The greatest differences are for the small signal case and are due to the compression of the calibration curve at small signal levels which results in greater inaccuracies of reading the value of the signal.

Figure 10. Comparison of Scintillation Index Measurements. S. I. measured directly from calibration and conversion curve vs. S. I. measured with machine computation of $P_{max} - P_{min}/P_{max} + P_{min}$; small signal case—average level approximately 1/4 chart width (10-15 mm)
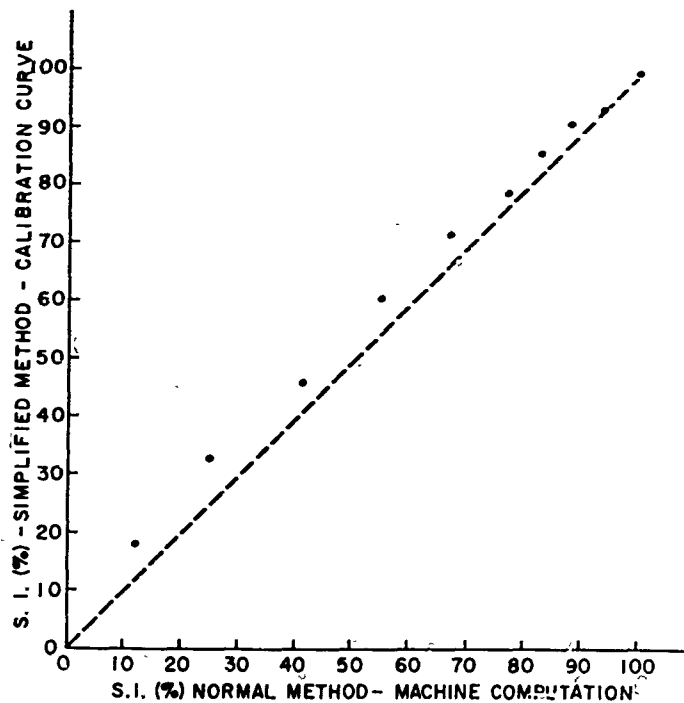
12

Figure 11. Comparison of Scintillation Index Measurements. S.I. measui ed
directly from calibration and conversion curve vs. S.I. measured with machine
computation of $P_{max} - P_{min}/P_{max} + P_{min}$; medium signal case—average level
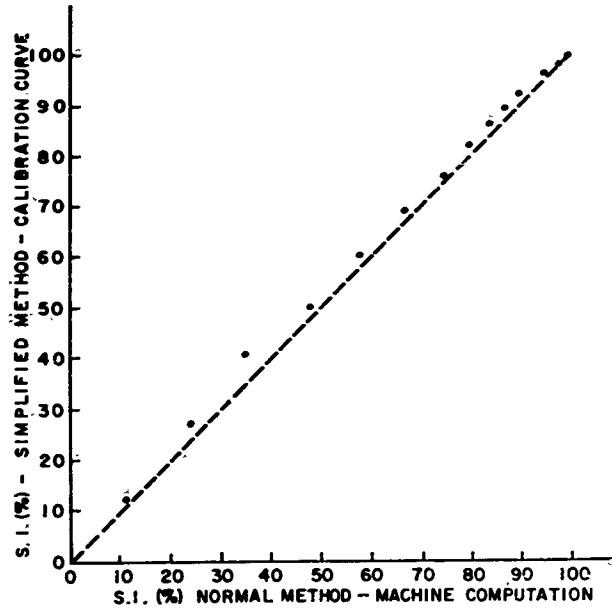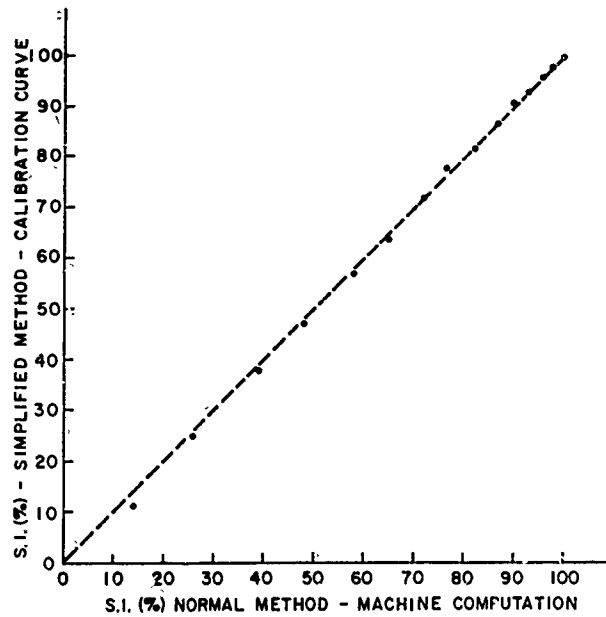approximately 1/2 chart width (20-30 mm)

Figure 12. Comparison of Scintillation Index Measurements. S.I. measured
directly from calibration and conversion curve vs. S.I. measured with machine
computation of $P_{max} - P_{min}/P_{max} + P_{min}$; large signal case—average level
approximately 3/4 chart width (30-35 mm)

If the simplified method is to be applied for analysis where there is a small signal-to-noise ratio and the deflection on the chart due to the sky background temperature is appreciable compared to the signal, the receiver calibration must be correctly applied so that only the deflections from the signal are being measured.

4. CONCLUSION

In summary, it is felt that only a relative measure of scintillation index is necessary to describe amplitude fluctuations caused by ionospheric irregularities, and that the simple measure S.I. $= \frac{P_{max} - P_{min}}{P_{max} + P_{min}}$, which was defined earlier, should be used. To obtain the best accuracy when comparing scintillation data, the records should be accurately calibrated on a power base. If scintillation index is scaled from chart divisions and the law of the detector is known, the index values can be converted to a power base with a small decrease in accuracy, as compared to scaling from a signal generator calibration. Comparison of data without the benefit of a calibration or knowledge of the detector characteristic can lead to errors of a factor of 2 or more. This is evident from Figure 3 where the apparent S.I., as indicated by chart divisions, is very small for the AGC mode and largest for the linear power mode. The simplified method of scaling S.I. gives adequate accuracy for statistical studies.

Reference

Briggs, B. H. and Parkin, I. A. (1963) On the variation of radio star and satellite scintillation with zenith angle, J. Atmos. Terr. Phys. 25:339.

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*	2a. REPORT SECURITY CLASSIFICATION
Air Force Cambridge Research Laboratories (CRP) L. G. Hanscom Field Bedford, Massachusetts 01730	Unclassified
	2b. GROUP —

3. REPORT TITLE

A PROPOSED INDEX FOR MEASURING IONOSPHERIC SCINTILLATIONS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Scientific   Interim·

5. AUTHOR(S) *(First name, middle initial, last name)*

Herbert E. Whitney
Chester Malik

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1968	20	1

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
	AFCRL-68-0138
b. PROJECT, TASK, WORK UNIT NOS. 4643-02-01	
c. DOD ELEMENT 6240539F	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d. DOD SUBELEMENT 681000	ERP No. 284

10. DISTRIBUTION STATEMENT

1 - Distribution of this document is unlimited. It may be released to the Clearing-house, Department of Commerce, for sale to the general public.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
TECH, OTHER	Air Force Cambridge Research Laboratories (CRP) L. G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

Signals from radio star sources and satellites are regularly used for studying ionospheric irregularities. Amplitude and phase deviations can be imposed on the signals from these sources as they traverse the ionosphere. A parameter frequently used to describe the magnitude of this scintillation effect is scintillation index.

An experiment was designed to correlate various methods of making scintillation measurements; observations were made at 40 MHz using the ionospheric beacon, S-66. It is shown that when the law of the receiver detector is known, a conversion method allows comparison of data and statistics on scintillation index.

A simplified method of scaling scintillation index is described. The accuracy of the simplified method is determined by a comparison with measurements of scintillation index by machine computation.

DD FORM 1473 1 NOV 65