# ABSOLUTE CALIBRATION OF SOLAR RADIO FLUX DENSITY IN THE MICROWAVE REGION

H. TANAKA
*Toyokawa Observatory, Research Institute of Atmospherics, Nagoya University,*
*Toyokawa, Japan*

J. P. CASTELLI
*AFCRL Sagamore Hill Radio Observatory, Hamilton, Mass., U.S.A.*

A. E. COVINGTON
*Radio and Electrical Engineering Division, National Research Council, Ottawa, Canada*

A. KRÜGER
*Zentralinstitut für Solar-Terrestrische Physik, Heinrich-Hertz-Institut, Berlin-Adlershof, D.D.R.*

T. L. LANDECKER
*School of Electrical Engineering, University of Sydney, Australia*

and

A. TLAMICHA
*Ondřejov Observatory, Academy of Sciences, Ondřejov, Czechoslovakia*

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**Abstract.** The absolute calibration of solar radio flux density in the microwave region, which showed considerable discrepancies until 1966, has become completely uniform through international cooperative work. A complete history is described to avoid confusion, and correction factors are derived to convert the published values into absolute values for long series of routine observations. It is also shown that the most reliable calibration can be made by using a large pyramidal horn and by using sky and room temperature as calibration standards.

## 1. Introduction

The single-frequency radio patrol of the Sun is classical, but the need for precise observations at properly spaced frequency intervals has been increased as the basis for more advanced observations, especially for spectral studies of radio bursts and radio active regions.

This requirement can be fulfilled only when the observed data taken at different places, times and frequencies are unified through absolute calibrations.

At the beginning of the cooperative observations, the intercomparison of the daily observed values was a difficult problem. The compiler of the radio part of the *Quarterly Bulletin on Solar Activity* tried to derive approximate correction factors statistically, the result of which had been entered in the Bulletin every year until 1957. But these correction factors were not fully reliable because they were not based on absolute calibrations. It is also true that the accuracy of daily calibrations was generally

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poor in those early days. However, owing to the increased need for accuracy supported by the progress of the technique, the internal consistency of each series of observations has become fairly good in recent years. Nevertheless, the absolute calibrations made at different stations had discrepancies of as much as 30% in 1966.

In these circumstances, Commission V of URSI at the General Assembly in Munich, 1966, resolved to organize a working group to solve this problem. The Working Group tried to reach a conclusion within three years, but it was not fully successful. It took as long as six years before reaching a comprehensive conclusion.

Many papers have been published on the absolute calibration, but some of them have been found to be incorrect. The aim of this paper is to review how progress on this subject has been made for these several years, and to describe the final and successful conclusions.

## 2. History of the Work on Absolute Calibration

The history of long-term routine observations in the microwave region is summarized in Figure 1. It is seen that only a few have continued for more than one solar cycle, and most of the observations now being conducted at many frequencies have a history of only several years.

At the start of regular observations around the year of 1950, absolute calibration was a difficult problem. It was a common practice to estimate the absolute values by using an approximate gain of the antenna based on radar and communication techniques together with an approximate sensitivity derived from experiments with insufficient accuracy. One of the first attempts to derive more acurate absolute values was made at Toyokawa in 1951 at a frequency of 3750 MHz, which was followed by similar experiments for the Ottawa 2800 MHz series. Even for these series of observations, the absolute errors have been found to be 6% and 10% respectively. Later experiments and comments concerning absolute calibration are described in Table I in the chronological order of the events rather than in the order of publication.

The first main event occurred in 1964 when the HHI (Heinrich-Hertz-Institut, Berlin Adlershof) group pointed out after completing their experiments made by the standard field method, that the values at Toyokawa on 10–30 cm wavelengths were much too low. This conclusion had been strengthened by the fact that their values connected smoothly with the values at Ottawa on 10.7 cm. Being surprised by this result, the Toyokawa group made experiments in 1965 concluding that both the HHI 20 cm and Ottawa 10.7 cm values were much too high. This discrepancy in the results led to the formation of the Working Group of URSI in 1966.

In 1967–68, the HHI group made an experiment with a horn on 20 cm and found that the new values agreed with those of Toyokawa. Then the discrepancy between Ottawa and Toyokawa or HHI became a serious problem. This could not be solved until 1971, when a true pyramidal horn was built at Ottawa based on a suggestion made at the URSI Assembly in Ottawa, 1969.

We have learned through long discussions a very simple and well-known fact,

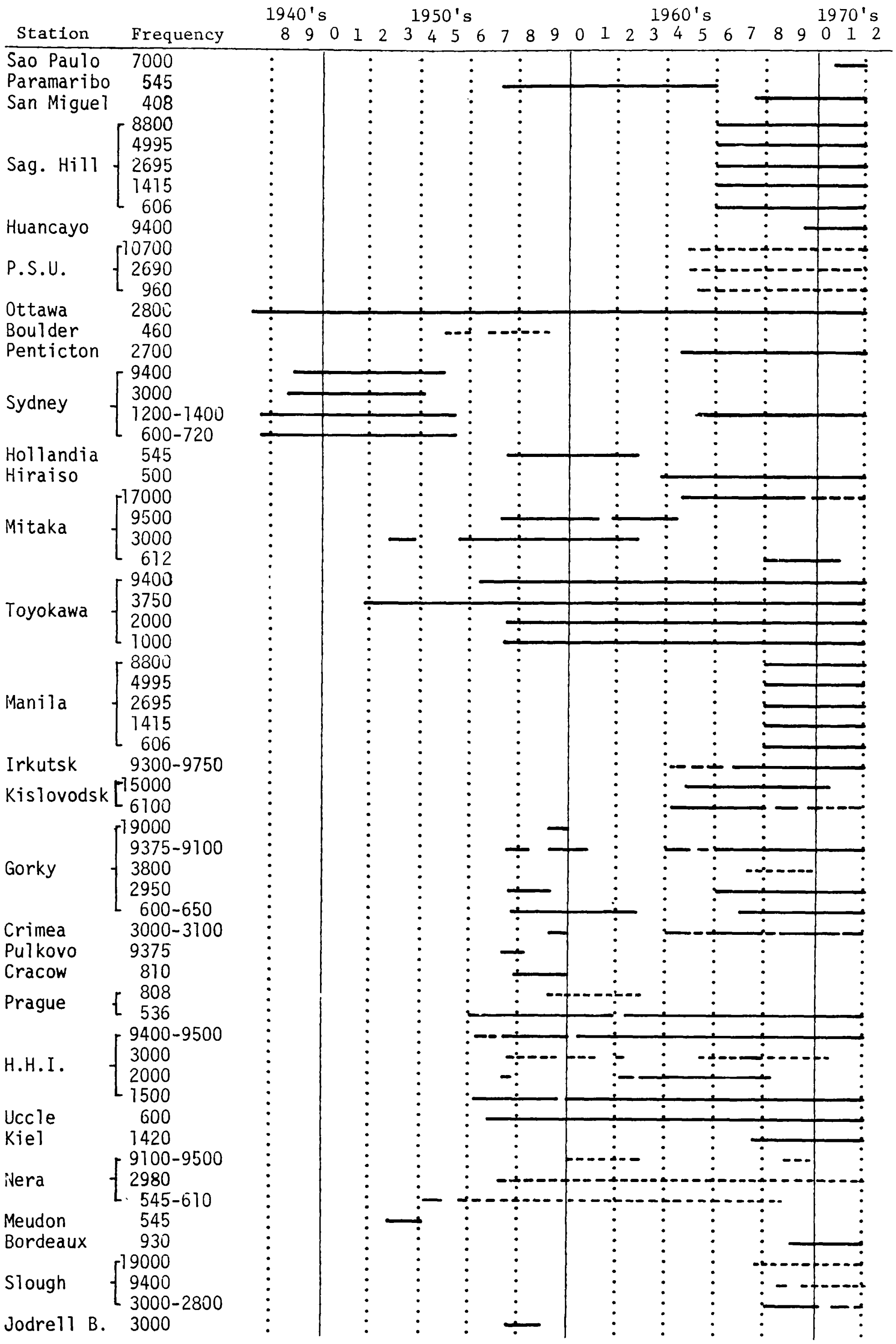

Fig. 1. Summary of the history of routine solar radio observations in the microwave region, ------ signifies burst only.

TABLE I

History of the work on the absolute calibration

| Year | Station | Progress | Retrospective remarks |
|---|---|---|---|
| 1951 | Toyokawa | Absolute calibration with a horn (Tanaka *et al.*, 1953) and the measurement of sky temperature, 0–5 K (Tanaka and Kakinuma, 1953), were made for the Toyokawa 3750 MHz before regular observation started in November 1951. | How difficult it was without the use of an isolator (Tanaka and Kakinuma, 1954). |
| 1952–53 | Ottawa | Absolute calibration with a horn and the measurement of sky temperature, 5.5 K, were made and it was found that the previous values [later called Series A] had to be multiplied by about 1.18 (Medd and Covington, 1958). | This correction factor was about 10 % too much. |
| 1955 | Toyokawa | Comparison of Ottawa 2800 MHz with Toyokawa 3750 MHz revealed a seasonal change of calibration, and the calibration procedure at Ottawa was doubted (Tanaka, 1955). | From a different point of view, high accuracy of both series was proved (Covington and Medd, 1954; Covington, 1959). |
| | Ottawa | Calibration for the Ottawa 2800 MHz was changed based on the experiment made in 1952–53 and by taking into account the Earth's background emission [later called Series B] (Medd and Covington, 1958). | |
| 1958 | HHI | The first absolute calibration on 20 cm was made using a single-frequency transmitter, and obtained 40 % higher values than those on the Toyokawa spectrum (Michel, 1964). | This experiment was not published. |
| 1960 | Toyokawa | The first absolute calibration with a horn was made at 9400 MHz and a preliminary correction factor of 1.04 was obtained (Tanaka, 1964). | |
| 1960–61 | Tübingen | Absolute measurements were made at 3750 MHz by estimating the antenna gain with the measured pattern and scattering factors, and obtained 5 % lower values than those at Toyokawa (Urbarz, 1964). | It is still doubtful whether this excellent result was due to the method or simply by chance. |
| 1962 | Prague | A proposal was made on the international unification of calibration during the IQSY, but unfortunately it was not successful (Tlamicha, 1962). | This would have stimulated the 1964 HHI experiment. |
| 1964 | HHI | Absolute calibration on 20 cm was made by a standard field method using a noise transmitter. They obtained more than 40 % higher values than the smoothed Toyokawa spectrum (Michel, 1964; Krüger and Michel, 1965; Mollwo *et al.*, 1965). | This challenging conclusion led to the formation of the WG. |

*Table I (Continued)*

| Year | Station | Progress | Retrospective remarks |
|---|---|---|---|
| 1964 | HHI | Absolute calibration on 3 cm with a horn showed full agreement with the Toyokawa 9400 MHz (Wiener and Krüger, 1964). | No problem was found on 3 cm from the beginning. |
| | Leningrad | A method of absolute calibration which had been used on 2 cm using an artificial Sun and the Moon was introduced. Accuracy was estimated to be ±5 %, but no comparison of data was made (Nagnibeda, 1964). | The Moon seems to be a too weak source as a cm-region calibrator. |
| 1965 | Toyokawa | Absolute calibration was made with new horns at 1000, 2000 and 3750 MHz. Preliminary correction factors were found to be 1.11, 1.08 and 0.99 respectively. This showed serious deviation from the HHI results (Tanaka and Kakinuma, 1966a). | These experiments were made stimulated by the 1964 HHI results. |
| 1966 | Ottawa | Corrections for atmospheric attenuation were taken into consideration and applied to the daily calibration (Medd, 1961; Covington, 1966). Thus a new 'Series C' was born. | It is doubtful if this correction is necessary for the 'observed value'. |
| | URSI Munich | The situation was reviewed (Tanaka and Kakinuma, 1966b; Krüger, 1966) and the WG was formed (Tanaka, 1966). The existence of spectral humps near 1500 and 2800 MHz was suspected at HHI and Ottawa. The preliminary correction factors of 1.04 and 0.99 for the Toyokawa 9400 and 3750 MHz were revised to 1.08 and 0.96 respectively. | The situation was desperately bad. |
| | Sag. Hill | Absolute calibration using Cas. A had been made at 606 and 1415 MHz, which suggested much too high values of the HHI 1500 MHz. Calibration of Toyokawa 1000 and 2000 MHz was doubted to be a bad change. Calibration of 8800 MHz with the Moon showed good agreement with Toyokawa and HHI 9400 MHz (Castelli, 1966). | The first outside doubt about the HHI result. |
| | Sydney | Absolute calibration was made at 1420 MHz with a horn for several days in September and also in December. Though the mutual consistency of these two series was doubtful, they suggested for the first time that the HHI 1500 MHz values were much too high (Landecker, 1966). | The first direct opposition to the HHI result. |
| 1967 | Sag. Hill | A correction factor of 0.91 for the 606 MHz series was established from the repeated comparison with Cas. A (Castelli, 1967). | |

*Table I (Continued)*

| Year | Station | Progress | Retrospective remarks |
|---|---|---|---|
| | HHI | The preliminary results of calibration on 20 cm with a horn revealed that the previous calibration with a standard field method was wrong (Priese, 1967). | The first admission for the wrong calibration. |
| 1968 | HHI | Further experiments on 20 cm with the horn established a correction factor of 0.82. New calibration has been applied since April 1968 (Priese, 1969). The importance of smaller deviation of Ottawa 2800 MHz from the Toyokawa-HHI spectrum was pointed out (Priese, 1968). | The problem on 20 cm was solved. |
| | WG Report | Preliminary report was prepared and published since the most significant discrepancy was solved (Tanaka, 1968a). | The first success of the WG. |
| | Ottawa | Calibration with the original horn was made in June to October 1968 and the correction factor of 0.95 was obtained (Covington, 1968). It was pointed out that the provisional value of 0.92 in the 1968 WG Report was found to be incorrect. The situation had become worse. | The problem on 10 cm had been brought into relief. |
| | Toyokawa | The absolute measurements at 2695 MHz were made at Toyokawa, and it was found that there was no hump between 2000 and 3750 MHz. After reviewing the absolute experiments, the preliminary correction factors for 1000, 2000 and 3750 MHz derived in 1965 were corrected to 1.16, 1.05 and 0.94 respectively (Tanaka, 1968b). | The experimental error at either Toyokawa or Ottawa had become clear. |
| 1969 | URSI Ottawa | The situation was reviewed (Tanaka, 1969) and it was recommended that the WG be continued until a more definite result could be reached (Commission V, URSI, 1969). The members assembled a number of times including the visit to Goth Hill. It was pointed out that the change of flare angle near the throat of the Ottawa horn might be the source of error. | The WG was not terminated due to the 10 cm problem. But the meeting at Ottawa was quite successful. |
| | Ottawa | Owing to its deformation, the original horn was no longer considered reliable. A new model was put in service, and the correction factor of 0.95 was revised to 0.92 (Covington, 1969). This change reduced the deviation to what it was in the 1968 WG Report. | This was not the true solution of the problem. |
| 1970 | WG Report | The discussion at the Ottawa Assembly and the improved situation at the end of 1969 were reported (Tanaka, 1970). | This could not be called success. |

*Table I (Continued)*

| Year | Station | Progress | Retrospective remarks |
|---|---|---|---|
| | HHI | Absolute calibration on 3 cm showed good agreement with the revised [1.08] Toyokawa values. The correction factor for the HHI 9500 MHz was found to be 0.087 (Keiser, 1970). | |
| | HHI | Absolute calibration was made at 2980 MHz, and it was pointed out that if the Ottawa values were multiplied by 0.88, all the calibration would become consistent (Schmidt, 1970). | This experiment was the first referee for the 10 cm problem. |
| 1971 | Ottawa | The experiments with the true pyramidal horns showed good agreement with Toyokawa as had been suggested at the Ottawa meeting. The correction factor of 0.895 [recorrected the atmospheric absorption] was derived. This is fully consistent with the other experiments (Covington, 1971). | The problem of 10 cm was actually solved. The second and final success of the WG. |
| | Bell T.L. | Absolute flux at 16 and 30 GHz was derived (Wrixon and Hogg, 1971). No direct comparison has been made. | |

namely that the most reliable calibration in the microwave region can be made by using a standard pyramidal horn.

## 3. Correction Factors for Long Series of Observations

Now that the international unification of absolute calibration has been successfully achieved, we can derive a correction factor for any series of observations to convert the published values into absolute values. This can be done, however, only when the series is internally consistent for years, because it is not practical to derive correction factors monthly.

First of all, the ratios of 'monthly means of the observed daily values' of a certain series to those of a calibrated series at a neighbouring frequency have to be plotted as shown in Figure 2 to find an average ratio between these two frequencies. Then a normalized spectrum of the average flux of the calibrated series during the same period must be drawn as shown in Figure 3. The relative values obtained from Figure 2 can also be plotted as shown in Figure 3, and thus the most probable correction factor can be obtained. In Figures 2 and 3 are shown only the selected series in the microwave region which are now in operation, and the plots are based on the corrected values announced by the observatory. In Figure 3, plots labeled 'BTL' are based on the experiments made at Bell Telephone Laboratories in 1969–70 (Wrixon and Hogg, 1971). The correction factors thus obtained are summarized in Table II.

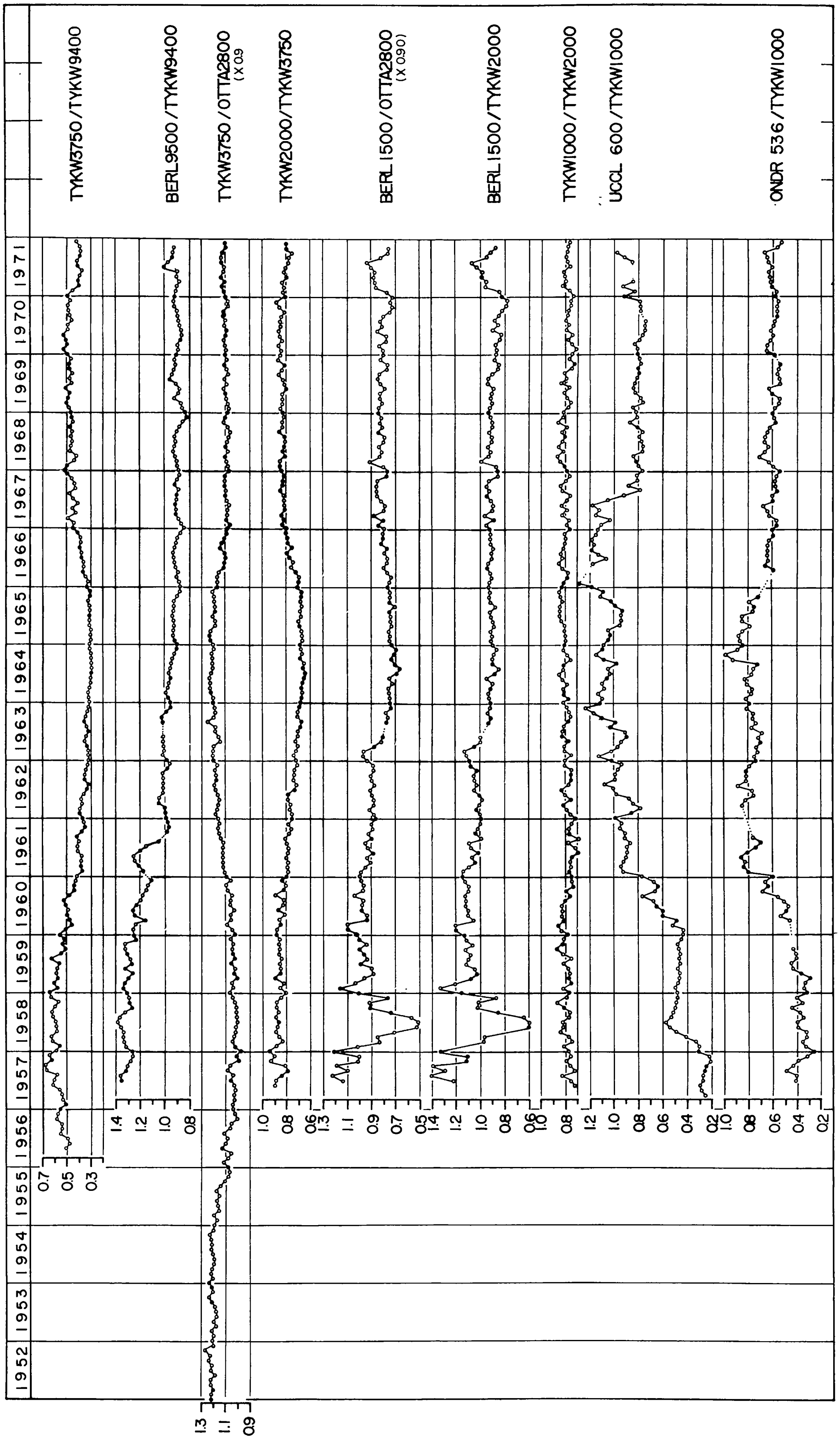

Fig. 2-1. Ratios of monthly mean values among various series of observations.

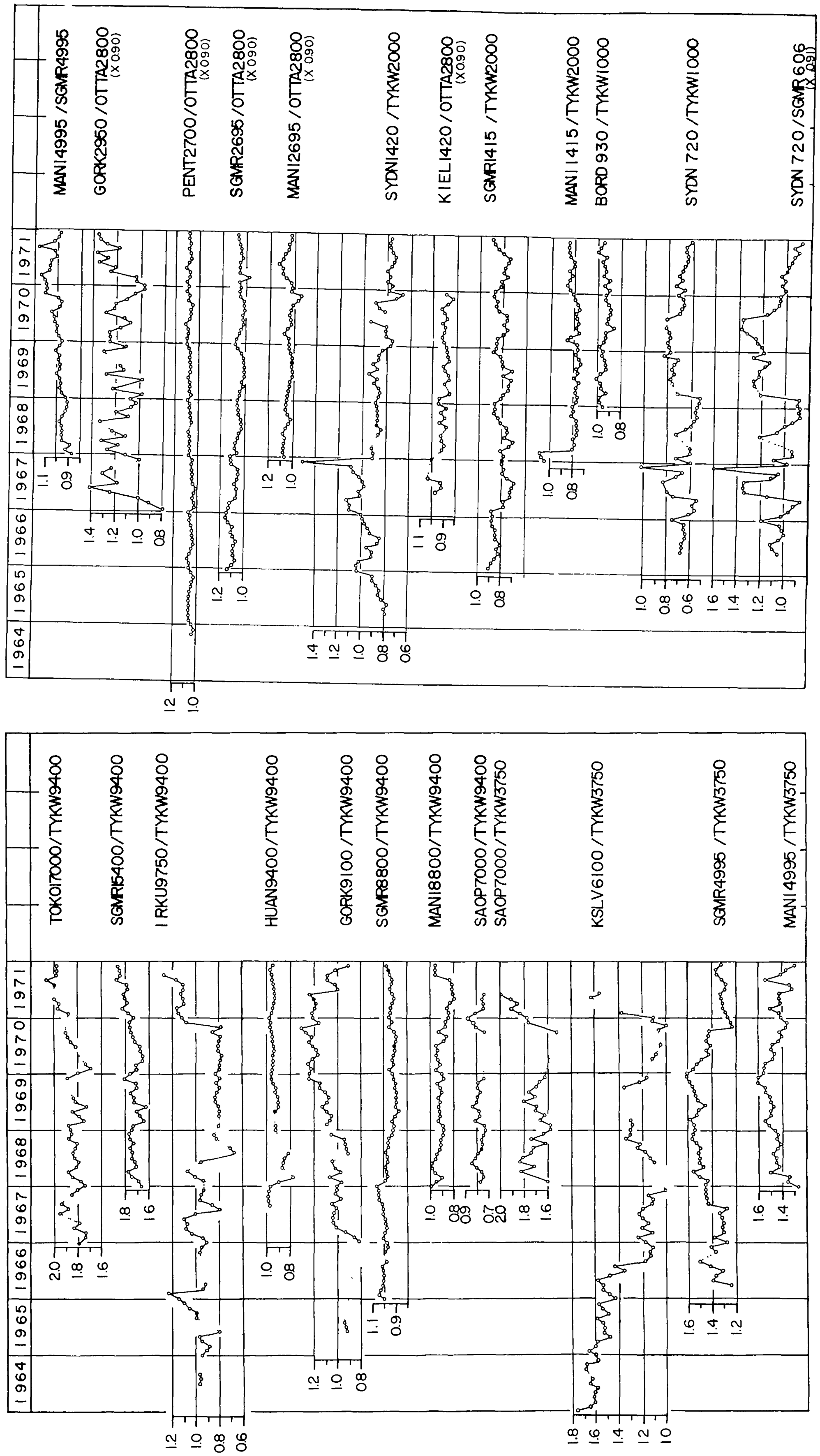

Fig. 2-2. Ratios of monthly mean values among various series of observations (cont'd).

It must be mentioned that the Ottawa values have not necessarily fallen exactly on the Toyokawa spectra during these 15 yr. A maximum upward deviation of about 4% occurred around the last solar maximum, and the next upward deviation of 3% occurred during 1964–66. The last deviation can be partially explained by the fact that the published Algonquin values were about 1.5% higher than the values at Goth Hill, but the first deviation has not been explained. The deviation since 1968 has been only less than ±1%.

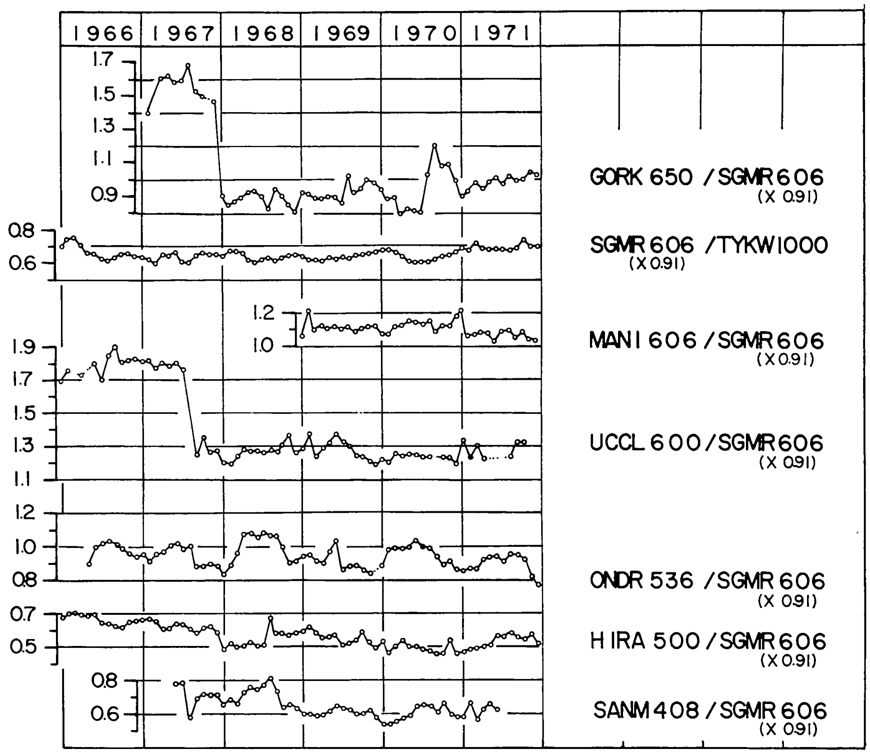

Fig. 2-3. Ratios of monthly mean values among various series of observations (cont'd).

## 4. The Most Reliable Method of Absolute Calibration

As mentioned on Section 3, the most reliable calibration in the microwave region can be made by using a pyramidal horn of moderate size, a few meters in length. The calculated gain of a pyramidal horn after Schelkunoff's formulae is believed to have an accuracy of about 1% when it is designed near the 'optimum horn'. It must be noted that there is a mistake in the definition of slant heights in the following reference, in which the above formulae are reproduced. That is, *Microwave Antenna Theory and Design*, MIT Radiation Laboratory Series, McGraw-Hill Book Co., 1949, p. 586.

In performing an absolute measurement of flux density, the use of a good isolator before the mixer and also the use of a linear amplifier including a square-law detector are of primary importance as is the common practise in measuring weak noise signals.

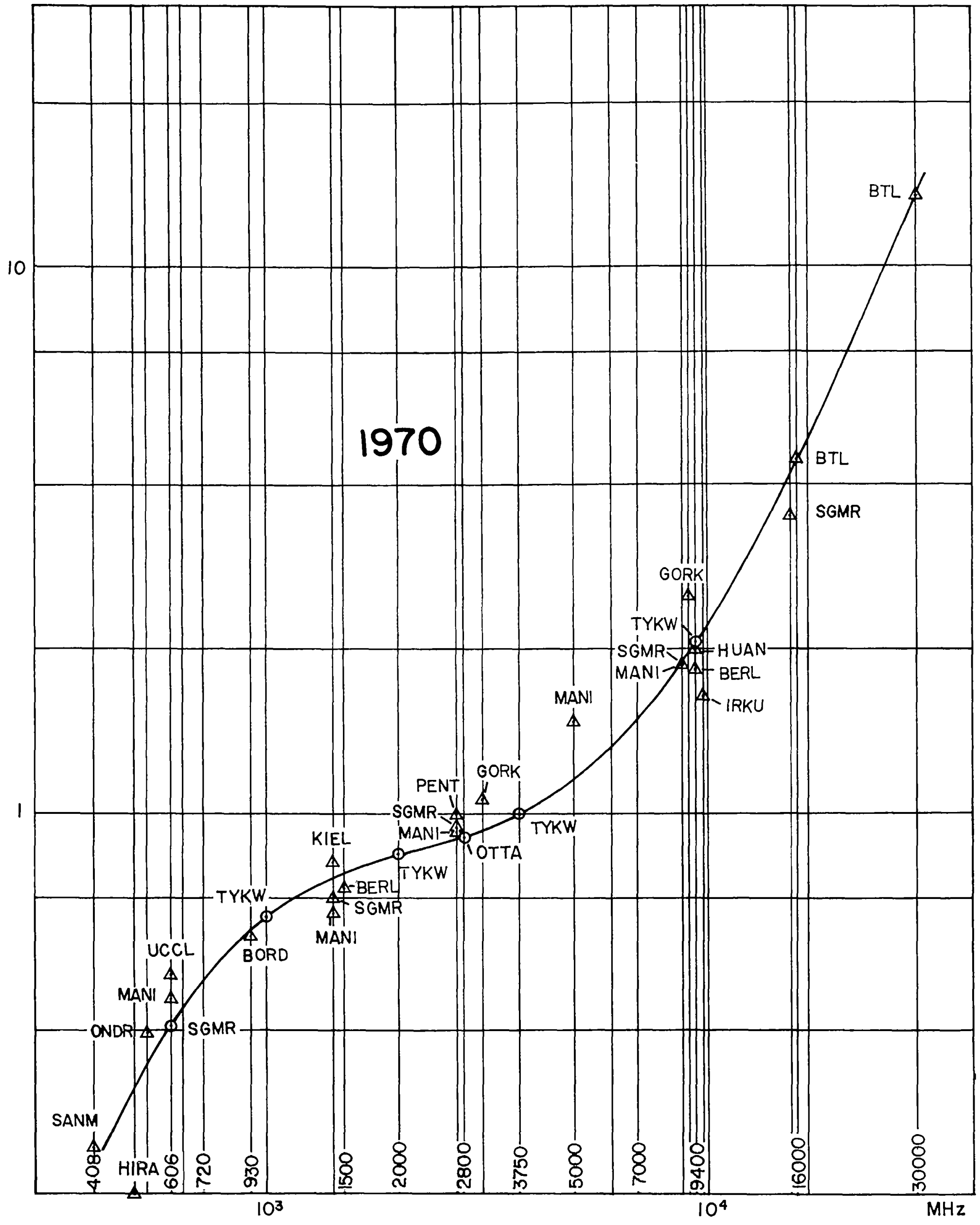

Fig. 3-1. Examples of normalized standard frequency spectrum with plots of observed relative mean values.

The schematic layout is shown in Figure 4. The following procedure to eliminate most of the ambiguities is recommended.

Four levels must be recorded on the chart as shown in Figure 5. $R_S$ and $R_z$ are the levels when the horn is pointed to the Sun and zenith respectively. $R_0$ is the level when the horn is covered by a resistive absorber, or is replaced by a resistive termination. In either case, direct sunshine on the resistor and the horn should be avoided to keep them close to the ambient temperature $T_0$. $R_b$ is the level when the antenna is pointed in the direction where $R_S$ was taken, but now with the Sun not present.

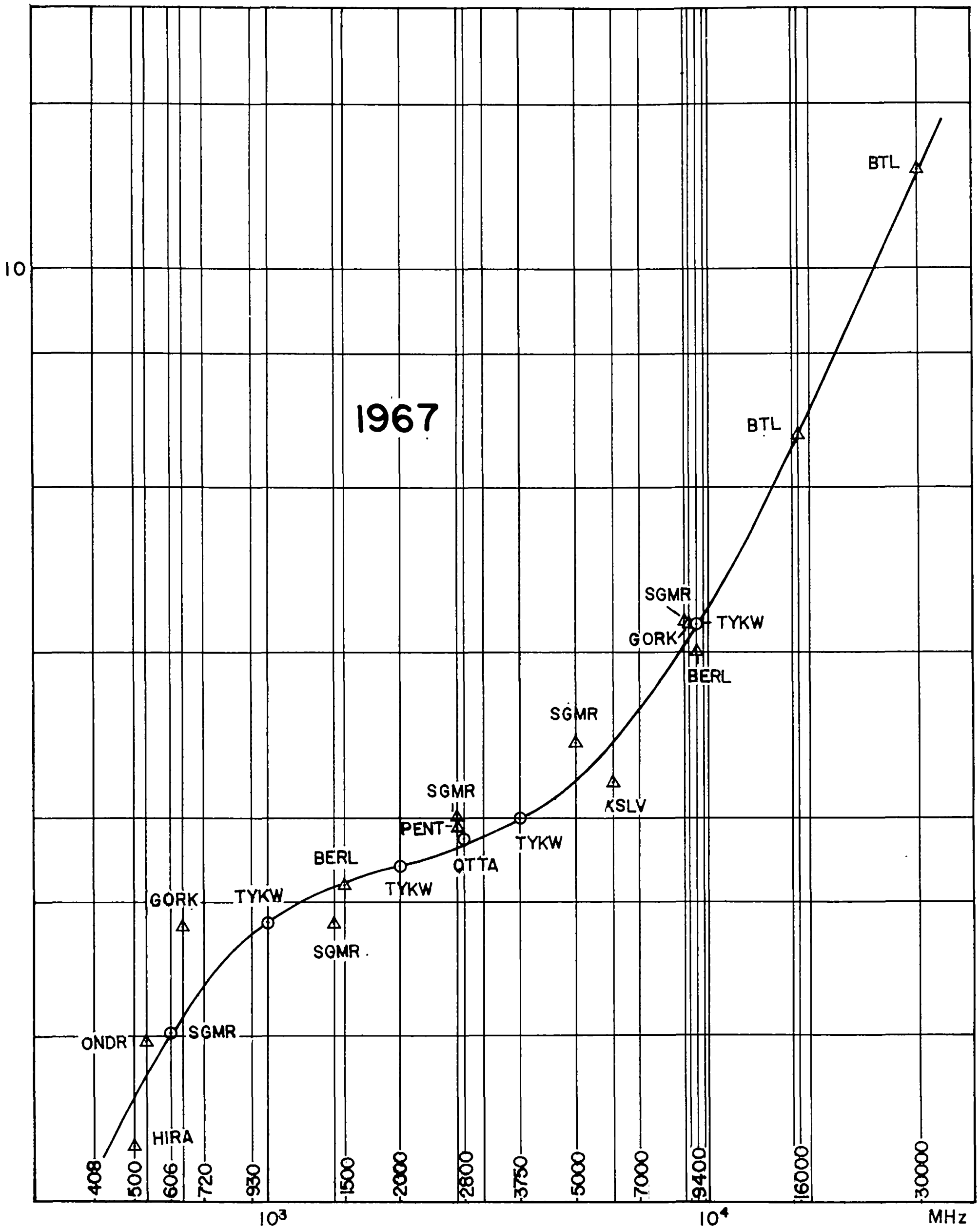

Fig. 3-2. Examples of normalized standard frequency spectrum with plots of observed relative mean values (cont'd).

Let the input noise temperature at the open end of the horn when $R_z$ and $R_b$ are taken be $T_z$ and $T_b$, and the increase of the input due to the Sun be $T_S$. Then,

$$\frac{T_S}{T_0 - T_z} = \frac{R_S - R_b}{R_0 - R_z} \quad \text{or} \quad T_S = (T_0 - T_z)\,\frac{R_S - R_b}{R_0 - R_z},$$

and thus $T_S$ can be obtained if $T_0$ and $T_z$ are known.

$T_z$ is composed of cosmic radiation, atmospheric radiation, and the Earth's radia-

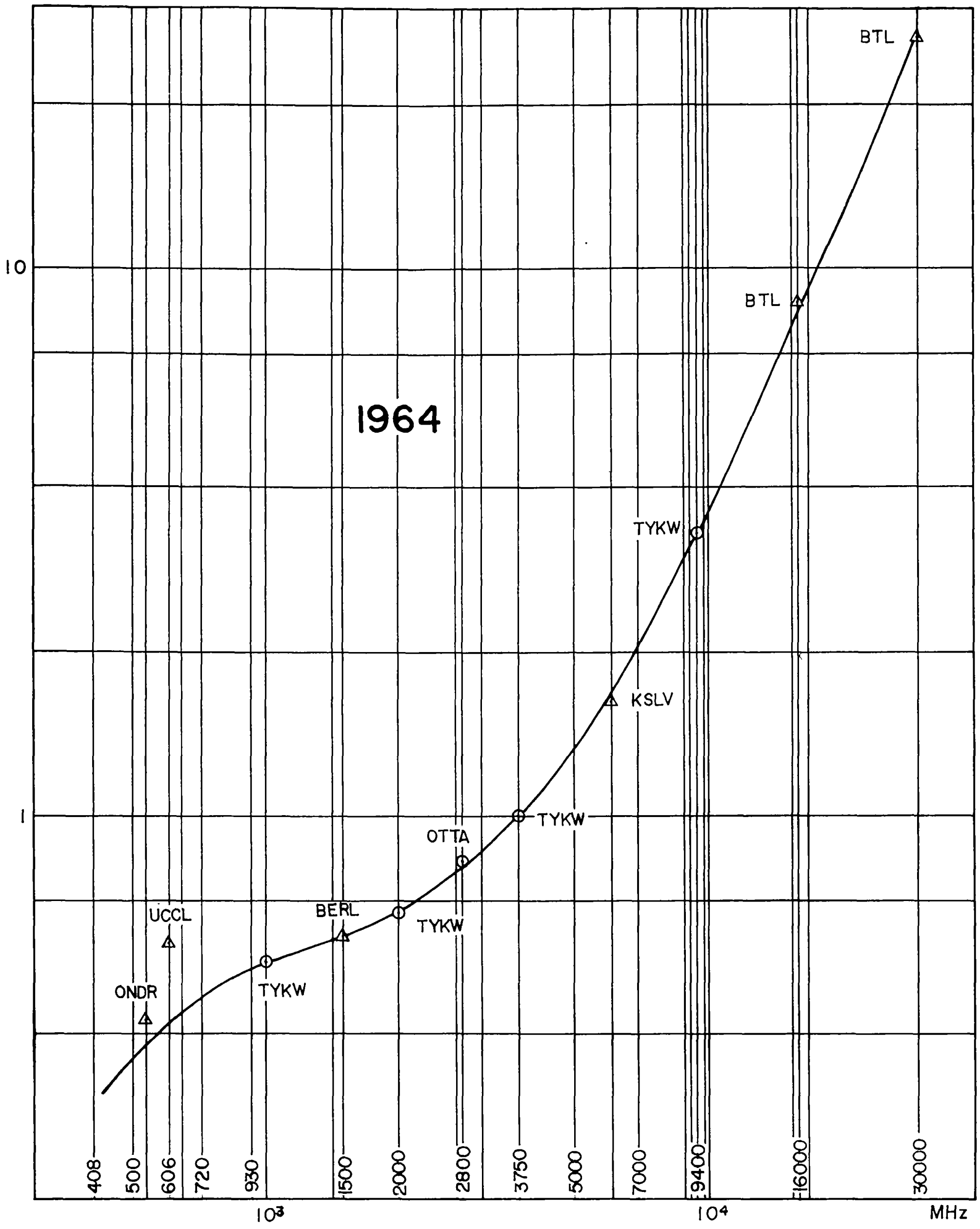

Fig. 3-3. Examples of normalized standard frequency spectrum with plots of observed relative mean values (cont'd).

tion from the back lobes of the antenna. Cosmic radiation is believed to be about 3 K above 10 cm wavelength but increases towards the longer wavelengths; atmospheric radiation, mainly due to the oxygen and water vapour molecules, is about 2 K between 10 and 3 cm. This decreases towards the longer wavelengths and increases towards the shorter wavelengths. Radiation due to the back lobes is estimated to be less than 1 K for a horn more than 40 wavelengths long, and about 4 K for one 10 wavelengths long. Thus $T_z$ can be estimated to be about 6 K near 10 cm for a horn of moderate size and a little more than 10 K near 30 cm. It is indeed a very difficult job to measure $T_z$ experi-

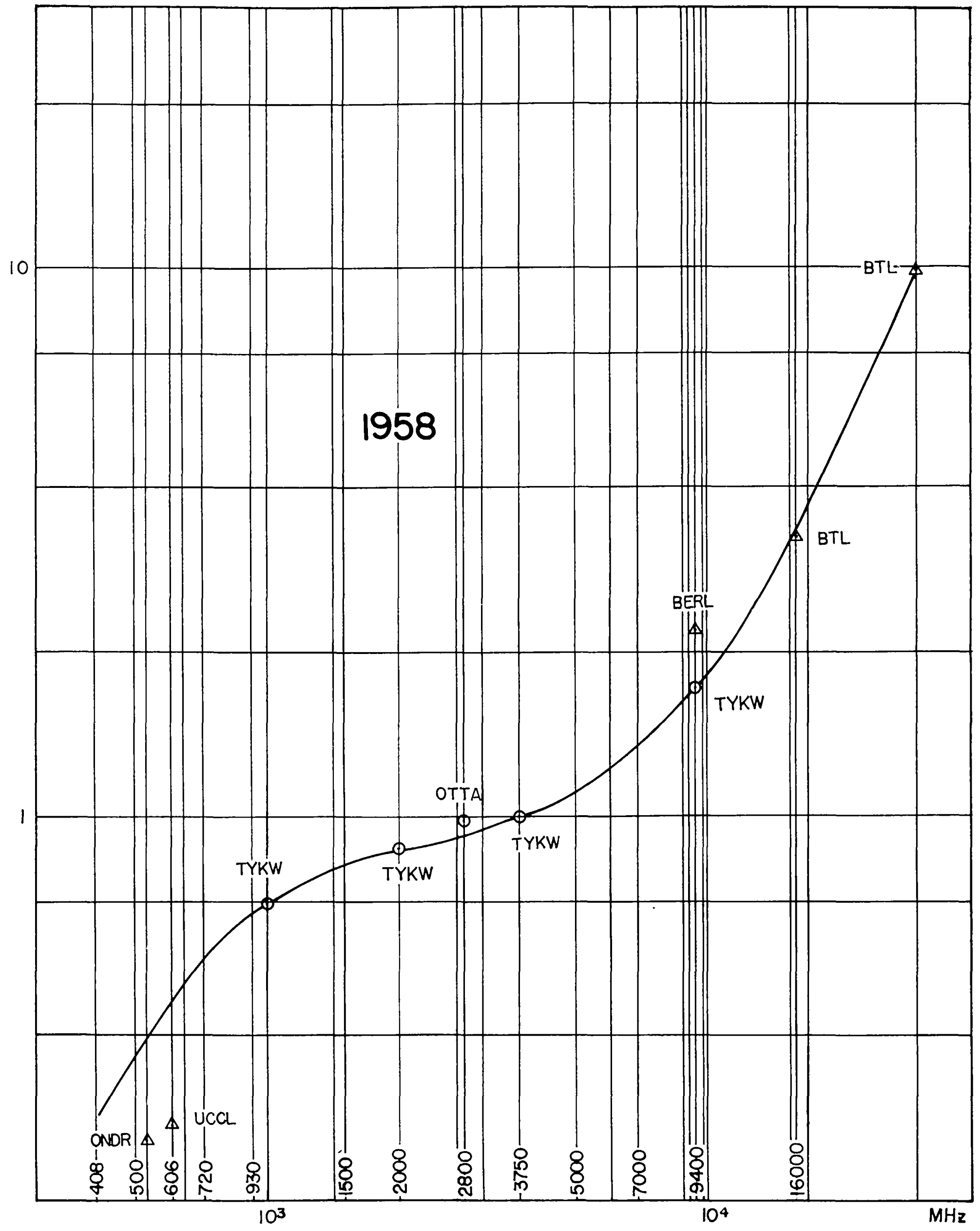

Fig. 3-4. Examples of normalized standard frequency spectrum with plots of observed relative mean values (cont'd).

mentally, but our present knowledge enables us to estimate the value of $T_z$ with an accuracy of several degrees Kelvin. This affects the absolute calibration by only one or two percent. This degree of accuracy is difficult to attain by any other method of calibration.

It is to be mentioned that $R_b$ can be obtained only after sunset by normalizing the sensitivity using $T_0$ and $T_z$, where $T_0$ will have changed considerably from that in the daytime.

The observed flux density can thus be obtained from $T_S$ with a calculated gain of the horn. But if one wants to express the flux density in terms of the incident flux

TABLE II

Summary of most probable correction factors for selected long series of observations

| Series of observation | Correction factors | | Corrections which have been commented on by the observatory | Remarks |
|---|---|---|---|---|
| | Period | Fact. | | |
| TOKO 17000 | 1967–1971 | 1.34 | | |
| SGMR 15400 | 1968–1971 | 1.20 | 1-AU correction after Apr 1969 | |
| IRKU 9750 | 1964–1968 | | | Unstable |
| | 1969–Nov 1970 | 1.31 | | |
| | Dec 1970–Sep 1971 | 0.96 | | Change of calib. |
| BERL 9500 | Jul 1957–1959 | 1.3 | | |
| | 1960–1961 | | | Unstable |
| | Oct 1961–1963 | 1.0 | | |
| | 1964–1965 | | | Gradual change |
| | 1967–1971 | 1.1 | | |
| HUAN 9400 | May 1969–1971 | 1.04 | | |
| TYKW 9400 | May 1956–1971 | 1.00 | See *Complete Summary of Daily Solar Radio Flux*, Toyokawa, Series-70. | |
| GORK 9100 | 1967–1968 | 0.96 | | |
| | Feb 1969–Nov 1969 | 0.86 | | |
| | Dec 1969–Jun 1971 | 0.80 | | |
| | Jul 1971–Dec 1971 | 1.0 | | |
| SGMR 8800 | 1966–1967 | 0.91 | | |
| | 1968 | | | Gradual change |
| | 1969–1971 | 1.00 | Nov 1970–Aug 1971 – × 1.14 | |
| MANI 8800 | 1968–1971 | 1.0 | | |
| | Aug 1970–Sep 1971 | | | Unstable |
| SAOP 7000 | Feb 1968–1969 | 0.9 | | |
| | Oct 1970–Jun 1971 | 0.9 | | |
| KSLV 6100 | 1964–Aug 1966 | 1.0 | | |
| | Sep 1966–1967 | 1.2 | | |
| | 1968–1971 | | | Unstable |
| SGMR 4995 | Apr 1966–Aug 1967 | 0.89 | 19 Jun 1969–15 Jul 1969<br>27 Aug 1969–30 Sep 1969 – × 0.91 | |
| | Sep 1967–Oct 1970 | 0.75 | | |
| | Nov 1970–1971 | 0.89 | 1 Nov 1970–31 Aug 1971 – × 0.845 | |
| MANI 4995 | 1968–1971 | 0.8 | | |
| TYKW 3750 | Nov 1951–1971 | 1.00 | See *Complete Summary of Daily Solar Radio Flux*, Toyokawa, Series-70. | |
| GORK 2950 | 1967 | | | Unstable |
| | 1968–1971 | 0.84 | | Monthly variable |
| OTTA 2800 | Feb 1947–1971 | 1.00 | Series C × 0.90 | |
| PENT 2700 | Nov 1964–1971 | 0.90 | | |
| SGMR 2695 | 1966–1968 | 0.90 | 9 Jun 1967–31 Aug 1967 – × 1.13 | |
| | 1969–1971 | 0.94 | | |
| MANI 2695 | 1968–1971 | 0.93 | | |
| TYKW 2000 | Jun 1957–1971 | 1.00 | See *Complete Summary of Daily Solar Radio Flux*, Toyokawa, Series-70. | |
| BERL 1500 | Jul 1957–1960 | | Jul 1957–Jun 1958 – × 2 | Unstable |
| | 1961–1962 | 0.88 | | |
| | Sep 1963–1971 | 1.0 | 1965–Mar 1968 – × 0.82 | |
| SYDN 1420 | Apr 1965–1967 | | | Unstable |
| | 1968 | 1.11 | | |
| | 1969 | 1.03 | | |

*Table II (Continued)*

| Series of observation | | Correction factors | | Corrections which have been commented by the observatory | Remarks |
|---|---|---|---|---|---|
| | | Period | Fact. | | |
| | | 1970 | | | Unstable |
| | | 1971 | 1.18 | | |
| KIEL | 1420 | 1968–1970 | 0.94 | | |
| SGMR | 1415 | 1966–1971 | 1.16 | | Seasonal variation |
| MANI | 1415 | Jan 1968–Mar 1968 | 0.88 | | |
| | | Apr 1968–1970 | 1.17 | | |
| | | 1971 | 1.10 | | |
| TYKW | 1000 | Mar 1957–1971 | 1.00 | See *Complete Summary of Daily Solar Radio Flux*, Toyokawa, Series-70. | |
| BORD | 930 | 1969–1971 | 1.02 | | |
| SYDN | 720 | Jun 1966–Mar 1969 | | | Unstable |
| | | May 1969–Jun 1970 | 1.0 | | |
| | | Sep 1970–1971 | 1.2 | | |
| GORK | 650 | 1967 | 0.7 | | |
| | | 1968–Jul 1970 | 1.2 | | |
| | | Aug 1970–Nov 1970 | | | Unstable |
| | | Dec 1970–1971 | 1.1 | | |
| MANI | 606 | 1969–1970 | 0.9 | | |
| | | 1971 | 0.93 | | |
| SGMR | 606 | 1966–1971 | 1.00 | All published values × 0.91 | |
| UCCL | 600 | 1957–1960 | | | Unstable and low |
| | | 1961–1965 | 0.75 | | |
| | | Jun 1966–Jul 1967 | 0.56 | | |
| | | Sep 1967–1971 | 0.8 | | |
| ONDR | 536 | Jul 1957–Oct 1959 | 1.6 | | |
| | | 1960–1961 | | Oct 1964–Dec 1965 – × 1.55 | Unstable |
| | | Apr 1962–1971 | 0.91 | Sep 1964–Oct 1964 – Uncertain | |
| HIRA | 500 | 1966–1971 | 1.4 | | |
| SANM | 408 | Jun 1967–Sep 1968 | 0.8 | | |
| | | Oct 1968–1971 | 1.0 | | |

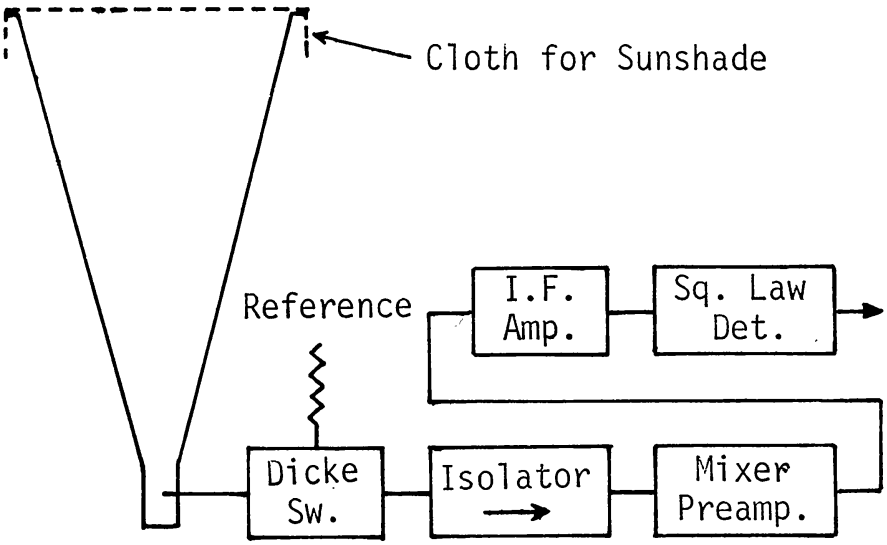

Fig. 4. Basic system for absolute calibration.

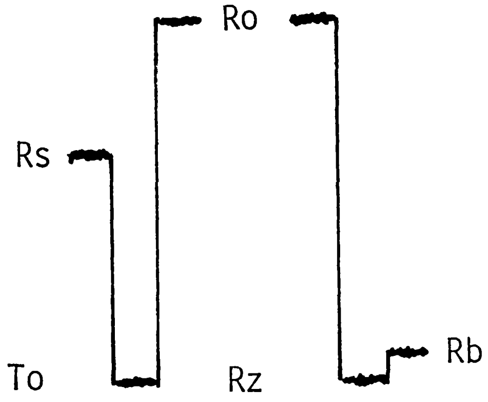

Fig. 5. Basic readings necessary for absolute calibration.

above the atmosphere, the effect of atmospheric attenuation must be taken into account. The correction factor can then be approximated by

$$\exp[\alpha \sec Z] \simeq 1 + \alpha \sec Z,$$

where $\alpha$ is the attenuation constant, of the order of 0.007 near 10 cm, and $Z$ is the zenith distance.

It is clear that this method is independent of the loss of the transmission lines, including that of the horn which is not easy to estimate. It is also independent of background radiation from the galaxies, the atmosphere and the Earth when the horn is pointed toward the Sun. The only weak point is that it cannot eliminate the cosmic anisotropic background in the direction of the Sun, if any, which will produce seasonal errors. This may happen on long dm wavelengths.

## 5. Daily Calibrations

Since the horn is inconvenient for daily calibrations, it is common practice to use a paraboloid on an equatorial mount. The beam of the antenna must be sufficiently broad to avoid different weights of sensitivity for different places on the solar disk. A HPBW of more than 4° is desirable, which corresponds to a center-limb sensitivity change of about one percent. A HPBW of 2° is the narrowest tolerable value; for this beam-width the sensitivity changes by as much as about 5% from the center to the limb. In this case, if the sensitivity of the system is calibrated with a horn with a broad beam when the Sun is quiet, the flux from a localized active region is calculated to be over or under-estimated by about 2.5% depending on whether it is located at the center or at the limb. This will not produce an error of observed total flux of more than ±1% even when an intense active region appears which produces one third of the total flux.

The desirable technique of calibration is the same as is described in the previous section. The observed values will be internally consistent within the accuracy of one or two percent if the calibration is made carefully every day. Failures of calibration are usually caused by carelessness, i.e., inaccurate pointing, gradual deterioration or damage to the components, unexpected deformation of the dish or the feed, and so on. It is usual that failures of this kind are noticed a few months later when an absolute calibration is made or when the data are compared with the other series of observations.

For automatic operation of the calibration procedure, a standard noise source composed of an argon discharge tube and a calibrated attenuator may be conveniently used, sometimes, together with a fixed directional coupler. This kind of system, however, will generally increase the sources of errors in calibration which creep in during a time scale of many years. In order to make the daily calibration reliable for a very long period, it is desirable to make a conventional calibration at least once a week by pointing the antenna toward the zenith.

## 6. Concluding Remarks

The international unification of absolute calibration has now been achieved in the microwave region. It is hoped that the observers who have the facilities will make absolute calibrations as frequently as possible in order to keep their daily values consistent for long periods of time. It is recommended that those who have no facility for absolute calibration compare their data with the other series of observations to keep good internal consistency.

For publication of the data, it is hoped that all the observers use absoute values as far as possible. If a change of scale is difficult as in the case of daily values of Ottawa which are widely used as the solar index, a correction factor to convert the published data into absolute values should be clearly indicated on the monthly report. For the values of distinctive events, however, it is strongly desirable to enter the absolute values because the frequency spectrum of the event is particularly important. It must be noted here that the problem of time constant which is sometimes very serious for the impulsive burst has not been solved.

Finally, it should be pointed out that many papers which have dealt with the spectra of the slowly varying component and of bursts must be revised more or less according to this final conclusion. Readers of the early papers are requested to be very careful in referring to them.

## Acknowledgment

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### Abbreviation of Stations for Table II, Figures 2 and 3

| | |
|---|---|
| BERL | Heinrich-Hertz-Institut, *Berlin* Adlershof |
| BORD | The Observatory, the University of *Bordeaux* |
| GORK | Radiophysical Research Institute, *Gorky* |
| HIRA | *Hiraiso* Radio Observatory |
| HUAN | Geophysical Institute of Peru, *Huancayo* |
| IRKU | *Irkutsk* Radioastronomical Observatory |
| KIEL | Radio Observatory, *Kiel* University |
| KSLV | *Kislovodsk* Radioastronomical Observatory |
| MANI | *Manila* Observatory |
| ONDR | *Ondřejov* Observatory |
| OTTA | National Research Council, *Ottawa* |
| PENT | Dominion Radioastronomical Observatory, *Penticton* |
| SANM | Observatory of Cosmic Physics, *San Miguel* |
| SAOP | Mackenzie University, *Sao Paulo* |
| SGMR | *Sagamore* Hill Radio Observatory |
| SYDN | University of *Sydney* |
| TOKO | *Tokyo* Astronomical Observatory |
| TYKW | *Toyokawa* Observatory, Nagoya University |
| UCCL | Belgian Royal Observatory, *Uccle* |

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