3-4 Development of the Measurement Technology of the Spurious Emission from Primary Radar

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In order to facilitate efficient use of frequency spectrum, ITU-R recommends the reduction of all unwanted emissions in line with the agreed international recommendations of the ITU. The unwanted emission control recommendation, for Radars requires the measurement of all unwanted emissions transmitted by the radar antenna including that of the spurious in a defined method of measurement detailed in a recommendation.

NICT have been conducting a research and development program to establish the required measurement site in Japan and the necessary measurement system. This paper will provide reviews of our activities at NICT on the project to date. In order to construct the measurement site that can meet the requirement of ITU-R M.1177, we have surveyed a number of potential sites in Japan and measured their electro-magnetic environment. Radar emission measurement experiments were also conducted at each site to enable the selection of the best suitable site from the potential list. For the measurement system requirements, a theoretical evaluation was conducted using simulation technique as well as performing real measurement experimentation. From our investigation, the following conclusions were obtained: The requirements in ITU-R M.1177 for the dynamic range, measurement distance (far field condition) and the measurement condition of rotating antenna under test are reasonable and must be adhered to. Resolution bandwidth (RBW) of the receiver, however, in the ITU-R M.1177 is found to be not sufficient and narrower bandwidth must be selected to be no more than 1/4 τ (τ: pulse width) in order to decrease the measurement error.

Keywords
Unwanted emission, Spurious emission, ITU-R, M.1177, Radar

1 Introduction

To ensure the effective use of radio frequencies spectrum, a reduction of the unwanted radio frequency emissions is required to be in line with the agreed international recommendation is a goal shared throughout the world. The ITU (International Telecommunication Union) has revised the regulatory limits of unwanted emissions and spurious emissions in 1997, stipulating its application from 2003[1].

In Japan, the law was revised as of December 2005, applying more rigorous regulatory limits relative to earlier regulations (however, a two-year transitional period was approved). Specifically in terms of primary radar, unlike other communications equipment, the law requires the establishment of the limit mask described below (−20 dB/decade; see also the bold line in Fig. 1) to enable control and identification of out-of-band and spurious regions.

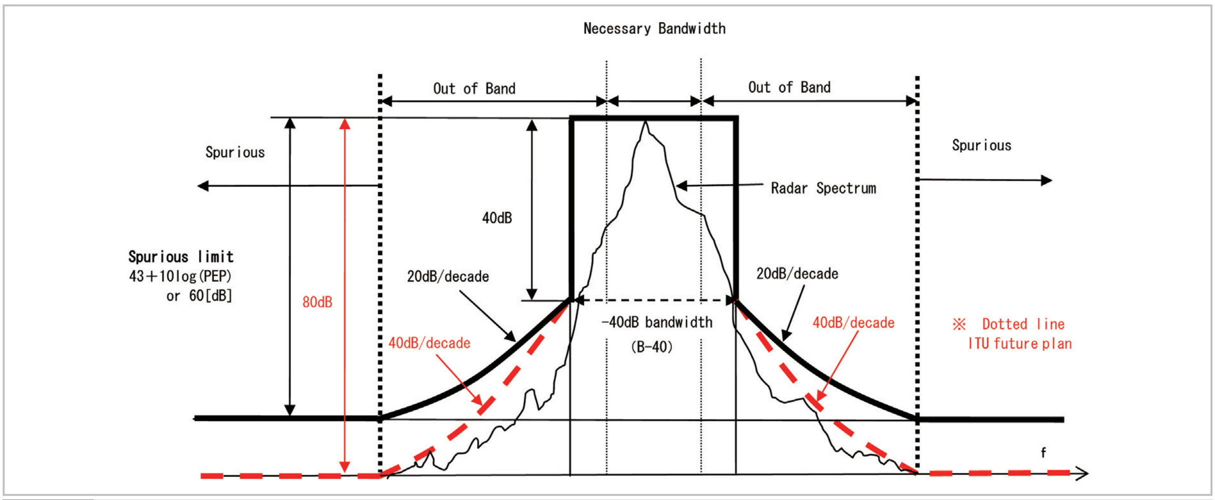


Fig.1 *Out-of-band and spurious regions*

To measure the unwanted emissions from radar systems, measurement methods has been set out and defined in ITU-R Recommendation ITU-R M.1177, recommendations approved by the ITU-R assembly must be employed[2].

The ITU-R M.1177 recommendation specifies two measurement methods: the direct method (measures the Air-Bourne radio frequency emissions radiated directly from the radar antenna), and the indirect method (which calculates emissions by measuring spectra at the feeding point of the transmitter-receiver within the wave guide separately from measurement of the antenna characteristics). In the case of the indirect method, even if the antenna and transmitter characteristics (measured separately over the entire target frequency range under measurement) are corrected together, the oscillation condition (i.e., the spectra) varies with changes in load depending on the transmitter, thus rendering accurate measurement totally impossible. As a result, the direct method is currently favoured.

ITU-R M.1177 requires a measurement dynamic range of 70 [dB] or higher, specifying that in the case of the direct method, the far-field antenna condition $(((2xD^2)/\lambda)$ {D: length of the antenna under measurement, λ: wavelength}—several hundreds of meters for marine radar, several km for meteorological radar) be met in measurement. From this perspective, two factors are critical for measurement according to ITU-R M.1177: the measurement system must provide a sufficient measurement dynamic range and the measurement location (site) must meet the far-field antenna condition.

Since fiscal 2004, NICT has been engaged, under a commission from the Ministry of Internal Affairs and Communications, in the development of a method for measuring spurious emissions from radar that is compatible with the new regulations slated to come into effect in Japan. Among its efforts NICT has conducted a wide range of surveys and studies aimed, for example, at establishing measurement sites and systems in Japan. At present, only two sites in the world are capable of far-field measurement: QinetiQ in Britain and the NTIA (National Telecommunications and Information Administration) in the US. Accordingly, we conducted an experiment to measure spurious radar emissions at the NTIA site in October 2004 in partnership with various members of the NTIA.

From the survey and study results obtained to date, we have concluded that accurate measurement will be difficult to achieve at NICT's current Koganei measurement site (outdoor site) if such measurement is to be conducted in accordance with the measurement method set out in ITU-R Recommendation ITU-R M.1177. There are several reasons for this conclusion, including the insufficient distance for measurement at the facility and the significant impact of external radio frequencies[4][5].

Thus it is clear that we must establish a new measurement site in Japan; accordingly, we are in the process of investigating potential locations.

In terms of the measurement system, on the other hand, it is critical to secure a sufficient dynamic range (70 [dB] or more); a study is now underway to find a way to overcome this hurdle. Among the methods we are currently exploring, one involves expansion of the dynamic range while appropriately controlling the power input to the spectrum analyzer; this is performed by combining a variable band rejection filter (V-BRF) capable of suppressing only the fundamental wave (i.e., the centre frequency) with a low noise amplifier (LNA).

This paper describes the survey and study results to date from two perspectives—i.e., based on considerations **2** and **3** mentioned above—for the measurement of spurious radar emissions, in accordance with the ITU-R M.1177 recommendation.

2 Measurement site

In reviewing measurement sites, we carried out the following survey and study to determine the potential use of NICT's current measurement site (the Koganei outdoor site) and the possibility of building a further site at another location in Japan.

2.1 Study on measurement distance (necessity of far-field conditions)

One of the measurement requirements of ITU-R Recommendation ITU-R M.1177 is that the far-field antenna condition must be met. NICT's measurement site has a maximum measurement distance of 100 m, with a number of on-site radar systems that do not meet the far-field condition. To verify the necessity of this requirement, therefore, we conducted an experiment to confirm the difference in spectra obtained when the far-field condition is met and when it is not.

The experiment was carried out at the NTIA site in the US, as there are only two sites in the world (QinetiQ in Britain and the NTIA) where the far-field antenna condition is met.

In this measurement, the spectrum analyzer was set to zero span and RBW steps of approximately $1/\tau$ with a sweep time equal to or exceeding the time required for a single rotation of the antenna, in accordance with ITU-R Recommendation ITU-R M.1177. A block diagram of NTIA's measurement system is shown below (Fig. 2).

Spectral measurements were performed on the same radar (marine radar; S-band 30 kW P0N 4.2 m slot antenna) in two states: one in which the far-field antenna condition was met and another in which it was not. The spectra obtained are shown below (Fig. 3).

An 11 dB difference was observed for the second harmonic and a 14 dB difference was observed for the third harmonic. It is clear from these results that spurious emissions may be underestimated if the far-field antenna con-

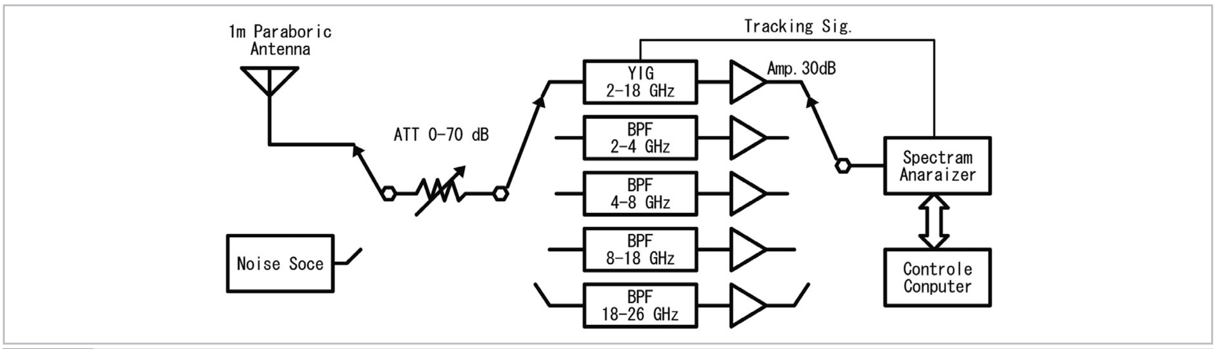


Fig.2 Measurement system block diagram

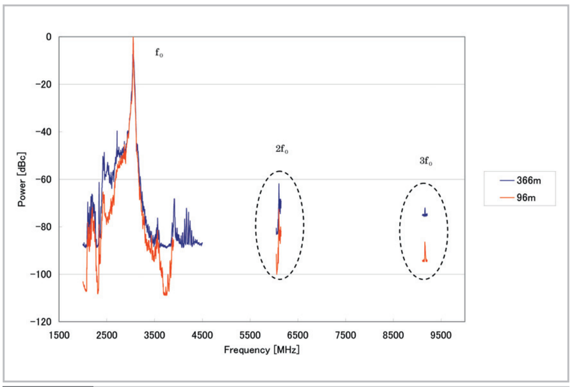


Fig.3 Difference in spectrum profile and contents was obtained to that in the far-field condition to the one when not in far-field condition.

dition is not met.

2.2 Survey on potential domestic sites

As demonstrated in Section **2.1**, it is essential to meet the far-field condition in order to establish a suitable measurement site (see Fig. 3).

It has thus clearly become necessary to build a new site in Japan; accordingly, we conducted a study under the following conditions:

(1) Location in an electromagnetic environment of minimal noise. The level of noise must be lower than that observed with the spectrum analyzer over the frequency range recommended by the ITU-R SM329-10[3], namely, from 1.5 GHz (cut-off frequency of the S-band waveguide) to 26 GHz (X-band measurement frequency range).

(2) Absence of other radio facilities in the vicinity. Radar systems often deliver high power output, resulting in possible mutual interference with other radio facilities.

(3) Provision of a distance that meets the far-field condition. A distance of roughly 360 m or more is required (in the case of an S-band 4.2 m slot antenna).

(4) Minimum multi-path effects such as ground reflection. ITU-R M.1177 stipulates that variation should be 3 dB or less when the antenna under measurement is moved vertically and horizontally by $\lambda D/2H$ (H: transmission point height, D: measurement distance, λ: wavelength).

(5) Maximum possible accessibility to the site.

Taking the above into consideration, we pre selected several locations as a result of a desk survey of potential sites and conducted surveys of the electromagnetic environment in these locations.

2.2.2 Survey of the electromagnetic environment

The electromagnetic environment was investigated for three (3) locations chosen as the most appropriate from a selection range of others as a result of a survey of potential measurement sites in Japan. To measure the electromagnetic environment, a measurement system (see Fig. 4) such as an antenna and spectrum analyzer (the equipment actually used for radar spectral measurement) was installed at the measurement locations, with the antenna beam pointed toward the location at which the system to be measured would be installed.

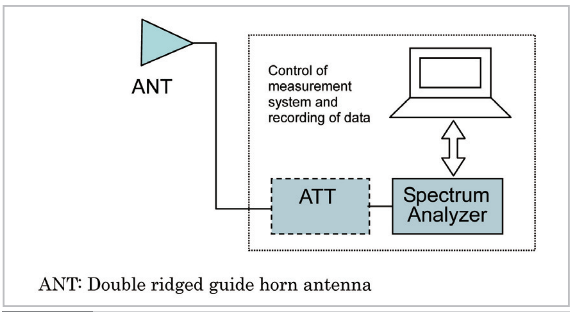


Fig.4 Electromagnetic environment measurement system

For the spectrum analyzer's resolution bandwidth settings (RBW and VBW), ITU-R M.1177 specifies that although "$1/\tau$" (τ: pulse width) may be used, if the resultant resolution bandwidth equals or exceeds 1 MHz or more, then 1 MHz is to be selected as the bandwidth. In the case of marine radars—the targets of the present experiment—the minimum pulse width of the majority of radar systems is approximately 80 ns. As a result, a resolution bandwidth of 1 MHz was used in all cases. Measurement was performed for an extended period of hours with MAX HOLD selected as the trace mode.

The following outlines each of the sites and lists the measurement results obtained under the above-mentioned conditions:

Location A

This candidate measurement site (location A) is in a corner of a cultivated field in a mountainous region that is isolated from mobile phones. The transmitter (radar) was located in front of a thick plantation at the foot of a mountain. The receiver (measurement vehicle) was placed approximately two terraced fields below. The distance between the transmitter and receiver was approximately 500 m, with an altitude difference of 10 m (including a transmission antenna height of 7 m and a reception antenna height of 10 m). The electromagnetic environment at this potential site was found to be -60 dBm or less (1 GHz to 26 GHz) (see Fig. 5).

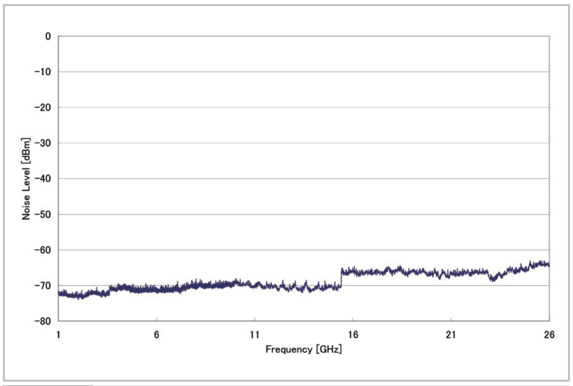


Fig.5 Results of measurement of electromagnetic environment at location A

Location B

Located in the mountains, this candidate measurement site (location B) is isolated from mobile phones, with a V-shaped gorge sandwiched between a thick plantation of trees on the north side (receiver side) and a narrow ploughed field on the south side (transmitter side). The transmitter was installed in a corner of the field, and the receiver was placed in a clearing near a forest trail. The distance between the transmitter and receiver was approximately 500 m, with a valley between the two devices. The electromagnetic environment at this potential site was found to return a value of −60 dBm or less (1 GHz to 26 GHz) (see Fig. 6).

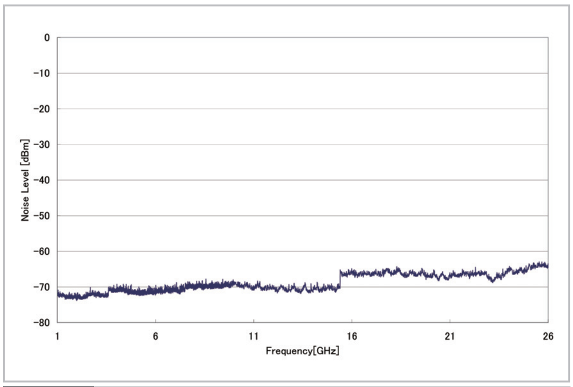


Fig.6 Measurement results for electromagnetic environment at location B

Location C

This candidate measurement site (location C) is more accessible than the remaining two sites, lying some distance from the centre of an urban area. Although surrounded by a highway and national road, the location is in a spacious, nearly flat meadow (300 m × 300 m; a former agricultural experimental station). The distance between the transmitter and receiver is roughly 100 m, with almost no difference in altitude (including a transmission antenna height of 4 m and reception antenna height of 6 m). Worst case emission in the electromagnetic environment was found to be at −57 dBm. All emissions encountered were in the low frequency region (1 GHz to 3 GHz) from expected sources such as mobile phones (see Fig. 7).

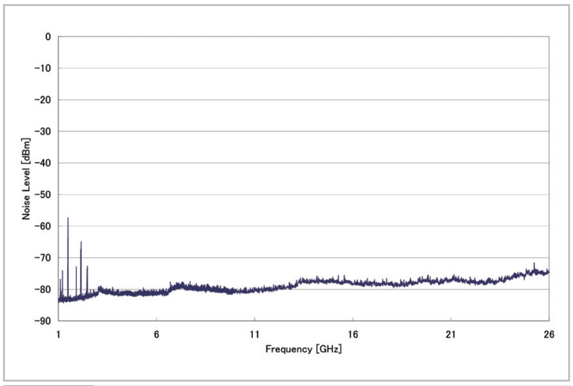


Fig.7 Results of measurement of electromagnetic environment at location C

2.3 Measurement experiment for spurious radar emissions

A Radar was installed in locations A and C (one at a time) for spectral measurement. In the present experiment, measurement was focused only on spurious emissions in the vicinity of the centre frequency (area shown in Fig. 1). The measurement method was in accordance with ITU-R M.1177 (see Fig. 11).

The specifications of the radar (X-Band marine radar) used in the experiment are as follows:

Fig.8 *Radar under measurement*

Fig.9 *Experimental vehicle (reception point side)*

- Radio frequency type: P0N, peak output: 25 kW, centre frequency: 9,410 MHz
- Minimum pulse width: 60 ns nominal, antenna: 4 ft (The far field of this system is 96 m.)
- Photos of the equipment used at the measurement sites are shown below.

At locations A, B, and C selected based on electromagnetic surveys, measurement experiments were conducted using marine type radar, and the acquired resultant data were compared with the results measured at the NTIA site in the US.

Topographically, the distances between the measurement locations and the radar under measurement at the time of the experiment were 450 m, 550 m, and 100 m, respectively, for locations A, B, and C.

The comparison was performed by first normalizing the spectral data (frequency range: 9 to 9.7 GHz) obtained at each site relative to the peak power and then comparing the corresponding envelopes (see Fig. 10).

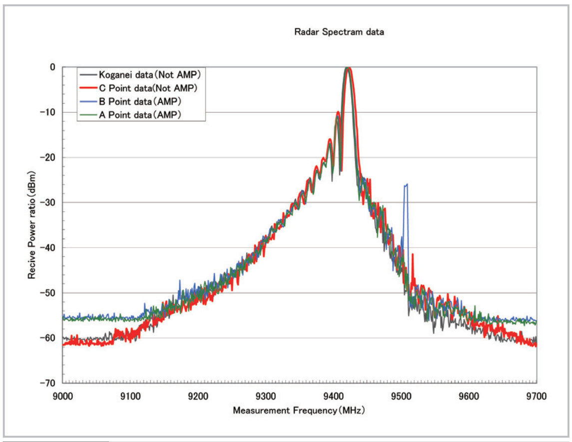


Fig.10 *Measurement results of spurious radar emissions at different sites*

From the above results, we confirmed the following:

(1) No significant differences were observed in measured values from the maximum measurement level to approximately −40 dB, with the measured data at all potential sites displaying reproducibility of the spectral shape. The measured data at location C had a centre frequency shifted slightly toward the higher frequencies as compared with the remaining two sites. This was due

to the properties of the magnetron, the oscillation source, compounded with low ambient temperatures at the time of the measurement.

(2) The measured data of −40 dB or below at all potential sites varied, presumably due to topographic factors including multi-path effects.

(3) Fluctuation in the received signal power level is likely to be caused by external interfering radio frequencies or the composite effect of combining more than one source. This was observed in several areas within the measurement results. These spectra, presumably reflecting the effects of aircraft radar or the like, merit further investigation. If aircraft, for example, can be identified as responsible, this effect could likely be eliminated by monitoring approaching aircraft or similar method.

Considering factors such as multi-path effects, the difference in altitude between the transmission and reception points should presumably be minimized. All sites tested featured an altitude difference, and under the present circumstances, this difference will hinder stable reception of extremely weak signals at or below −40 dB. Particularly at potential sites with a number of obstacles such as standing trees (locations A and B), this effect has been confirmed. In this respect, however, possible causes of signal level variations should be further investigated, as in these cases we are dealing with extremely weak signals.

3 Measurement system

As part of the overall study of spurious emission measurement methods and systems, several topics have been reviewed, including the actual performance of NICT's current measurement system and the adequacy of the requirements imposed by ITU-R M.1177 on measurement systems, including measurement methods. A summary of the study results is given below.

3.1 Confirming the performance of the measurement system

The NICT spurious measurement system is shown below.

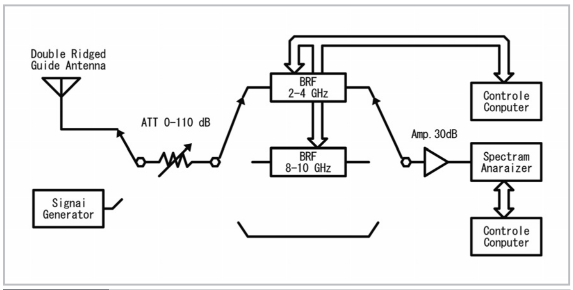


Fig. 11 *NICT spurious measurement system*

A comparison was made between the spectra obtained with this measurement system (measured at the NICT site) and those obtained with the NTIA measurement system (Fig. 2). The comparison results are shown in Fig. 12. In the case of the NICT outdoor site, the dynamic range was approximately 60 dB, falling short of the 80 dB or more required by ITU-R M.1177. This was primarily caused by suppression of the AMP input, and occurred because even though the main frequency component was attenuated by the BRF, the AMP developed inter-modulation at other frequency bands. In response to this result, several countermeasures are now under test, including the imposition of band limitations on the AMP and the use of a high-gain antenna.

3.2 Necessity of antenna rotation

The direct measurement method stipulated by ITU-R M.1177 requires that the antenna be

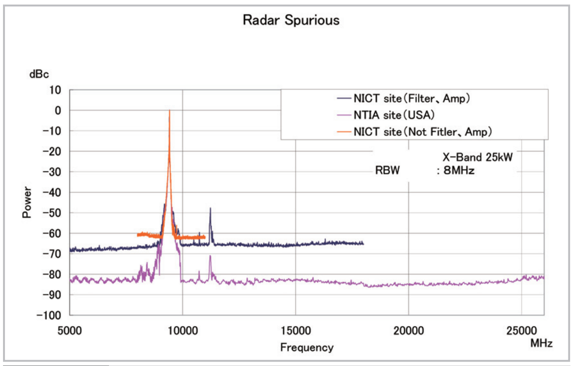


Fig. 12 *Comparison of dynamic range between NICT and NTIA sites*

rotated to measure radiated energy, as it is not known at which angle spurious emissions are radiated with respect to the antenna radiation surface. However, some radar systems take several tens of seconds to rotate their antenna by one complete turn. Because the antenna rotation time can significantly impact the measurement time, there is a movement within the ITU working group to advocate the deletion of this requirement. The necessity of antenna rotation was therefore verified.

Figure 13 shows two sets of measured data, one obtained by rotating the antenna and the other by maintaining the antenna facing the measurement antenna (in the direction of the main beam). An obvious difference was noted in the obtained spectra. This is because spurious emissions may be radiated in a direction that differs from that in which the fundamental wave is radiated. As a result, it has been confirmed that accurate spurious emissions cannot be determined if the antenna is not rotating.

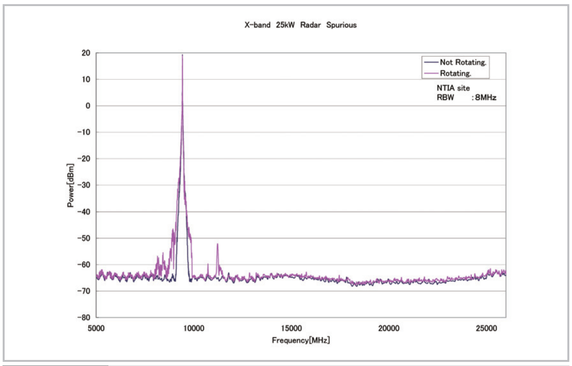


Fig.13 Comparison of radiation characteristics between rotating and non-rotating antennas

3.3 Evaluating effect of RBW

The direct measurement method according to ITU-R M.1177 requires that the RBW of the measurement system (spectrum analyzer) be set to $1/\tau$ (where τ is pulse width) and 1 MHz or less. Accordingly, ITU-R M.1177 stipulates that the spectrum analyzer should be set to zero span with the sweep time equal to or longer than the antenna rotation time (for one revolution) and the time required for the RBW steps; therefore, measurement may take a significant amount of time, depending on the value of $1/\tau$. This led to a movement within the ITU working group to argue for permission to use a wider RBW, with the aim of reducing measurement time. We therefore reviewed the difference in spectra obtained at different RBW settings.

3.3.1 Evaluation by simulation

Figures 14 through 17 show simulation results for measurement of an ideal rectangular wave with an ideal IF filter. Here, the pulse width (τ) = 1 μs.

Figure 14 shows the spectrum of a perfect rectangular pulse. Figure 15 shows the spectrum waveform obtained by measuring the pulse with a spectrum analyzer.

Figures 16 and 17 show the respective measurement results obtained with RBW settings of 100 kHz ($1/10\tau$) and 1.5 MHz ($1.5/\tau$). In the simulation results, different RBW settings produce spectral differences, clarifying that the 1.5 MHz RBW setting results in a lower side lobe.

Figure 18 shows simulation results for measurement of a trapezoidal wave (pulse width = 0.5 μs, rise/fall time = 20 ns, pulse repetition period = 1,000 μs) with a Gaussian filter in the same manner.

It is similarly obvious from these results that different RBW settings produce different measured values for the main and side lobes in trapezoidal wave measurement with a Gaussian filter.

3.3.2 Evaluation by measurement

3.3.2.1 Measurement using pulse modulated signal generator as signal source

Figures 19 and 20 show spectral measurement results with different pulse widths when feeding the spectrum analyzer with a microwave pulse generated by a signal generator and pulse modulator and varying the analyzer's RBW settings.

From the latter and by similar analysis, different RBW settings produce different measured values for the main and side lobes in pulse spectrum measurement using a signal generator. It should be noted, however, that

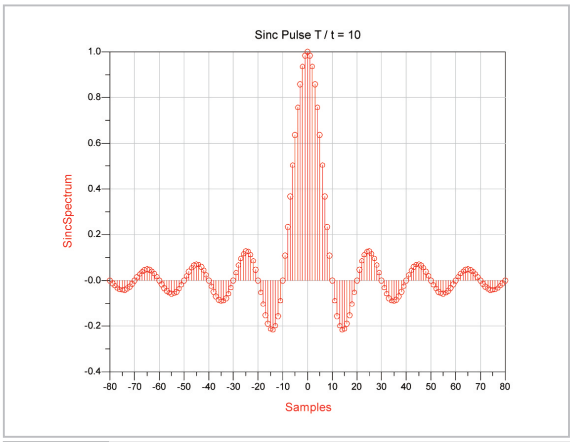


Fig. 14 Pulse amplitude modulated spectrum

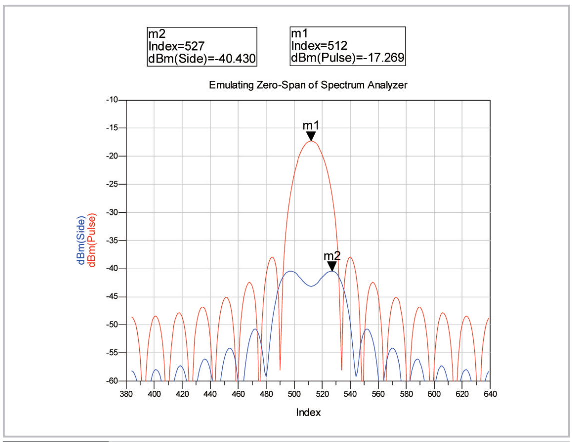


Fig. 16 Difference between main lobe m1 and side lobe m2 with 100 kHz RBW (17.9 dB)

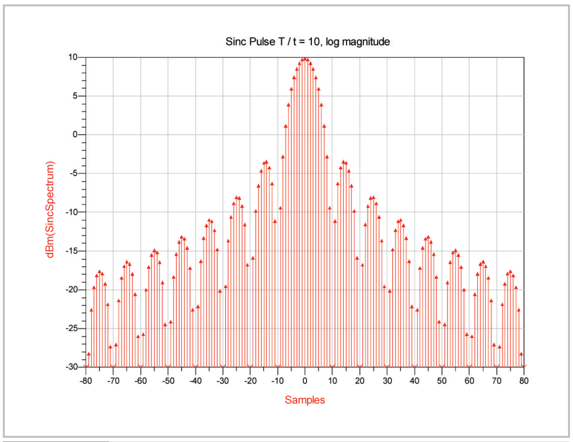


Fig. 15 Spectrum waveform displayed on the spectrum analyzer

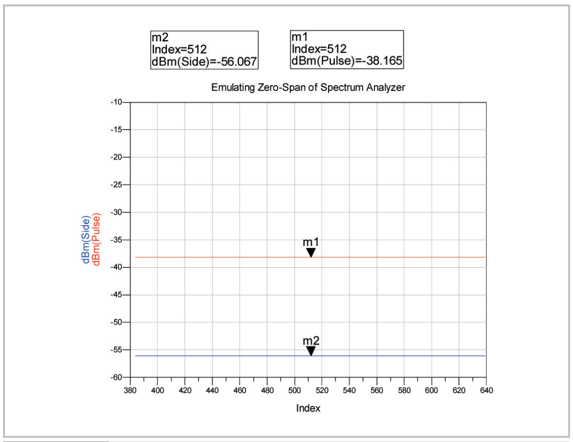
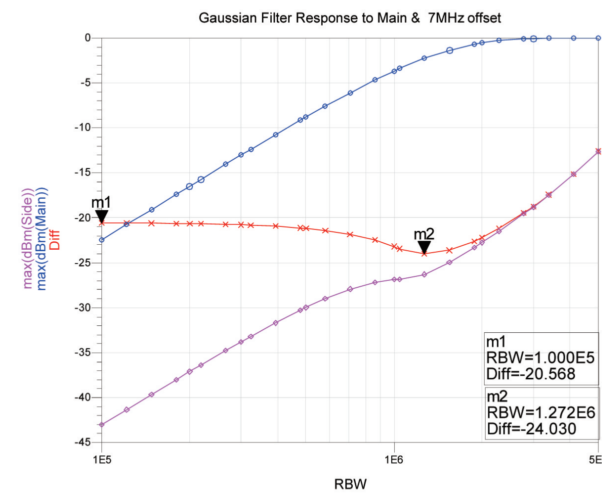


Fig. 17 Difference between main lobe m1 and side lobe m2 with 1.5 MHz RBW (23.2 dB)



RBW	Diff
100000.000	-20.568
121604.179	-20.580
147875.764	-20.598
179823.108	-20.624
200000.000	-20.644
218672.415	-20.664
265914.795	-20.722
300000.000	-20.771
323363.503	-20.808
393223.534	-20.936
478176.250	-21.127
500000.000	-21.182
581482.303	-21.411
707106.781	-21.838
859871.396	-22.481
1000000.000	-23.198
1045639.553	-23.457
1271541.394	-24.030
1546247.474	-23.615
1880301.547	-22.615
2000000.000	-22.220
2286525.260	-21.205
2780510.271	-19.470
3000000.000	-18.771
3381216.689	-17.435
4111700.797	-15.121
5000000.000	-12.615

Period:500[us], Pulsewidth: 0.5[us], Risetime: 20[ns], Falltme: 20[ns]

Fig. 18 Different measured values produced by different RBW settings with Gaussian filter

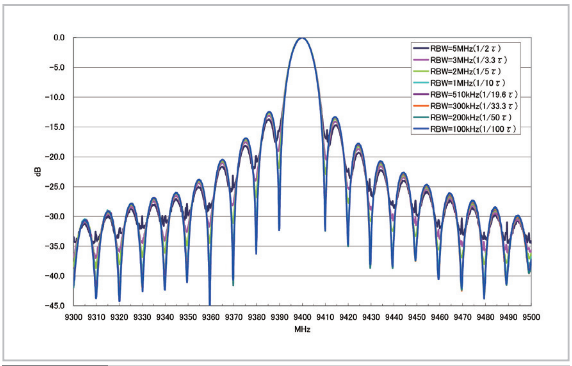


Fig.19 Spectrum with 0.1-ms pulse width

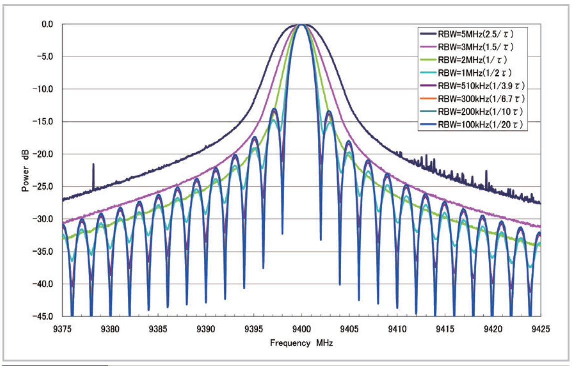


Fig.20 Spectrum with 0.5-ms pulse width

these results suggest that as long as the condition of RBW < 1/(4τ) is fulfilled, measurement error can be kept constant (approx. 0.5 dB or less).

3.3.2.2 Measurements using actual radar

Figures 21 through 23 show the results of spectral measurement when operating a magnetron based radar system and varying the spectrum analyzer's RBW setting.

As shown in Fig. 21, the spectrum waveform of an actual radar system is not an ideal rectangular wave, thus making it likely that the shape may change depending on the frequency component contents; it is also likely that the difference in measured values may vary with variations in the spectrum analyzer's RBW setting. However, the obtained results demonstrate that as long as RBW < 1/(4τ), measurement error can be kept at or below 0.5 dB.

Based on the above, it is clear that if we are to reduce measurement time using a wider RBW, we must also investigate the issue of permissible measurement error.

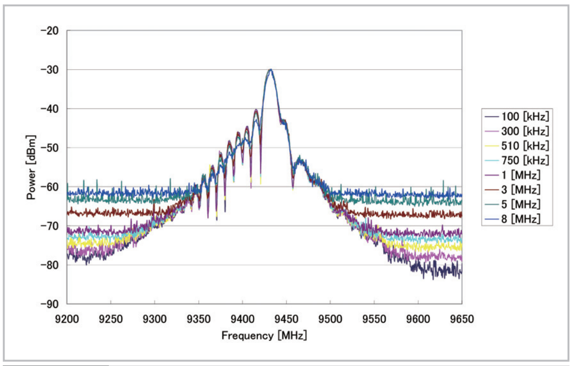


Fig.21 Radar system spectrum

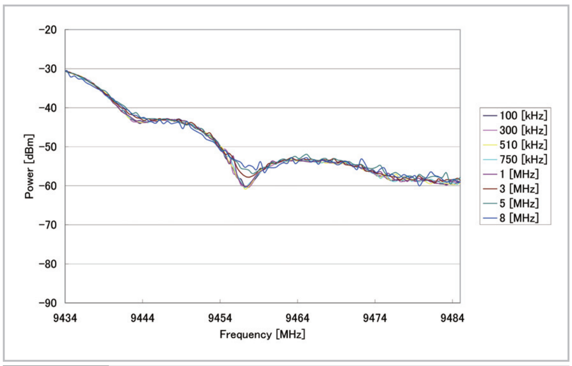


Fig.22 Enlargement of spectrum below centre frequency

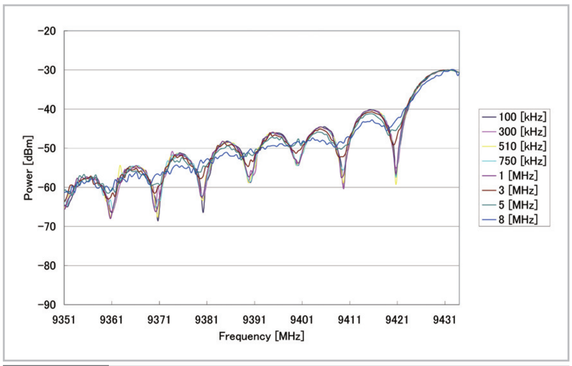


Fig.23 Enlargement of spectrum above centre frequency

4 Conclusions

4.1 Measurement site

4.1.1 Limitation of site capabilities

From the experimental results obtained at the NTIA, we confirmed that the radar antenna must be rotated during measurement as defined in ITU-R M.1177, as spurious emissions may be radiated in a direction different from that of the main beam.

Moreover, it has also been confirmed that the current NICT measurement system have a number of problems, including those related to dynamic range and measurement distance requirements, and therefore this system presents numerous challenges that must be resolved in order to ensure and achieve the required accuracy in measurement.

4.1.2 Survey on potential measurement sites in Japan

Potential sites were evaluated for the establishment of a standard site in Japan. Although further investigation is required—including an investigation of signal levels at −40 dB or less and spectra (spurious emissions) at frequencies other than the main frequency—our choice as the best potential site is location C, in line with the results of the investigation stated above for the various number of important points under consideration.

4.2 Measurement system

4.2.1 Necessity of antenna rotation

Spurious emissions are at frequencies that differ from the main frequency and may be radiated in a direction different from that of the antenna beam. Further, it has been confirmed that the antenna must be rotated to achieve correct measurement value in all directions

4.2.2 RBW study results

Based on the simulation and measurement results, we conclude that the relationship between the main and side lobe frequency bands obtained with a spectrum analyzer is represented by twice $1/\tau$ for the fundamental wave bandwidth and $1/\tau$ for the side lobe bandwidth. This means that increasing the RBW will results in reception of the signal in the adjacent lobe (i.e., the signal is in the opposite phase). As a result, significant error may be expected to occur depending on the RBW used when comparing the main and side lobes in terms of level difference. To eliminate this error, an RBW value of $1/(4\tau)$ or less is required.

However, using $1/(4\tau)$ RBW requires an even longer measurement time than at present.

In the future, we plan to survey measurement sites in Japan that will allow for far-field measurement and study techniques for establishing measurement methods for spurious radar emissions, taking RBW and permissible measurement error into consideration.

References

1 ITU-R Radio Regulations Appendix3 (Tables of maximum permitted power levels for spurious or spurious domain emissions), 2004.

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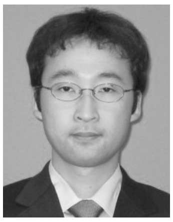

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