RECOMMENDATION ITU-R S.1512

Measurement procedure for determining non-geostationary satellite orbit satellite equivalent isotropically radiated power and antenna discrimination

(Questions ITU-R 231/4 and ITU-R 42/4)

(2001)

The ITU Radiocommunication Assembly,

considering

a) that some frequency bands are allocated for use by non-geostationary satellite orbit (non-GSO) satellite networks;

b) that the number of operational and planned non-GSO satellite systems has risen significantly in the past ten years;

c) that the interference experienced by such systems will become increasingly significant to other users sharing the frequency bands on a primary basis;

d) that operators of non-GSO satellite networks and administrations may wish to measure certain non-GSO satellite radiofrequency (RF) characteristics;

e) that the RF characteristics of non-GSO satellites are more difficult to measure than those of GSO satellites since the non-GSO satellites are moving with respect to the surface of the Earth,

recommends

1 that the test procedure in Annex 1 may be used as a guide to determine the equivalent isotropically radiated power (e.i.r.p.) and antenna discrimination of non-GSO satellites. Annexes 2 and 3 may be used as part of the measurement procedure to determine the maximum and minimum signal levels received by the test station.

ANNEX 1

Measurement procedure for determining non-GSO satellite e.i.r.p. and antenna discrimination

1 Introduction

The procedure which follows is intended to provide guidance to administrations wanting to perform repeatable measurements of the downlink e.i.r.p. and transmit gain pattern of operational non-GSO satellite.

2 Equipment requirements

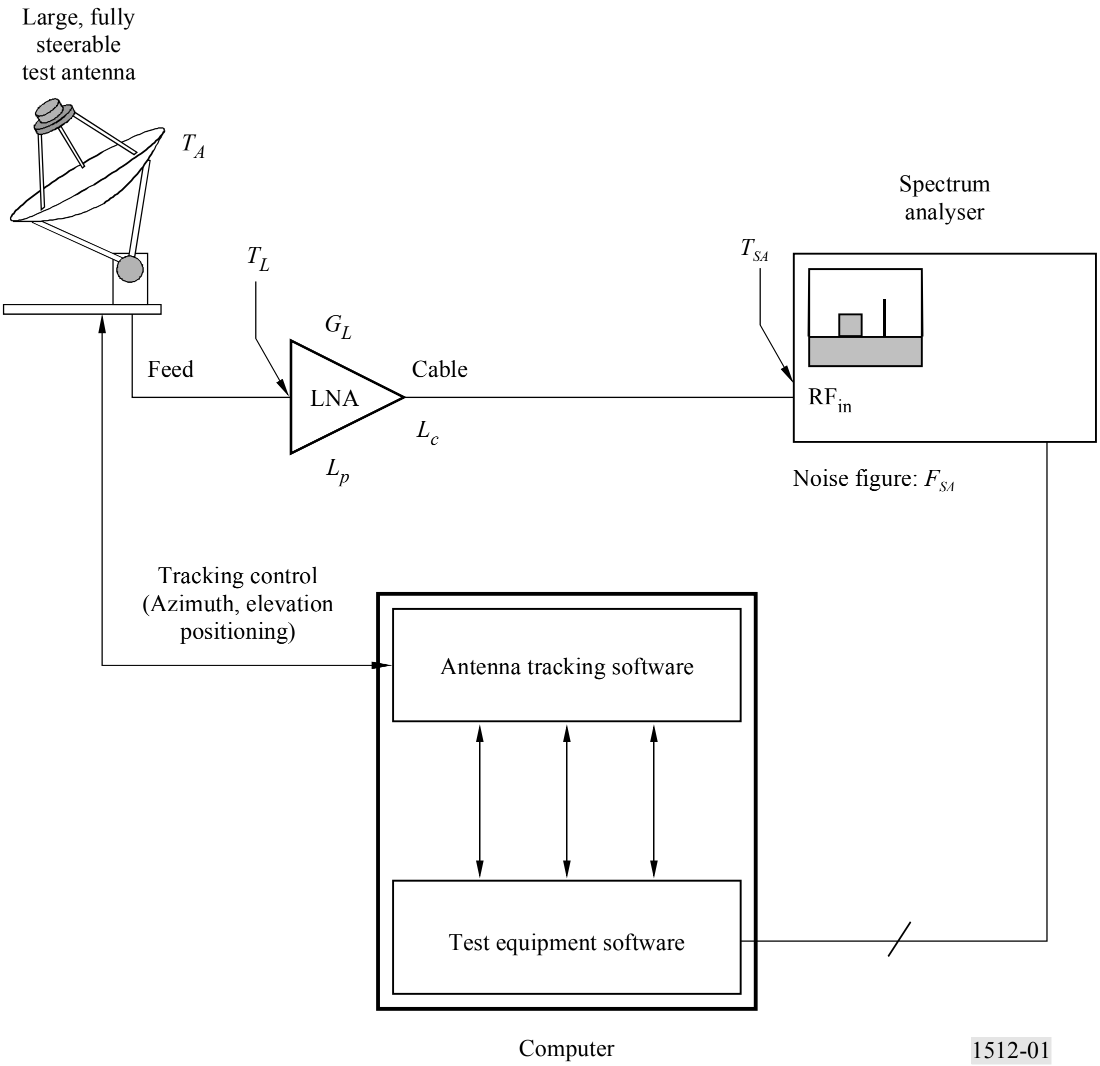
The test method involves the use of an earth station with a large, fully steerable antenna which is capable of tracking a satellite, a spectrum analyser capable of making the necessary measurements and a computer upon which operates an automated test program which can make the measurements and record the data on a file.

3 Description of measurement test-set

A block diagram of the measurement test-set is shown in Fig. 1. Each of the parameters shown in Fig. 1 is defined in Table 1.

FIGURE 1

Measurement test-set block diagram



Test antenna: The test antenna should be fully steerable over as much of the horizon as possible. The antenna reflector should be as large as possible so as to have a larger receive gain which translates in a larger dynamic range in which to make measurements. However the antenna slew rate should allow the antenna to remain pointed at the non-GSO satellite as it moves across the sky. The low noise amplifier (LNA) should have as low a noise temperature as possible so as to minimize the test equipment noise floor. The cable connecting the LNA to the spectrum analyser should be as short as possible and be of good quality so as to minimize the noise it adds to the test set-up.

Spectrum analyser: A spectrum analyser is required that has the capability of being digitally controlled by a computer and of transferring measured data back to the computer. A data bus connection between the computer and spectrum analyser is typically used for such applications. Next, the spectrum analyser should have a noise floor which is lower than the equipment noise floor, otherwise the spectrum analyser noise floor will limit the dynamic range over which measurements can be taken. This can be calculated analytically by determining the temperature of the set-up (Annex 3) and comparing it to that of the analyser. An alternate method to the analytical calculation is to attenuate the signal into the spectrum analyser by 10 dB and verifying that the $(I + N)/N$ has changed by less than 1 dB.

Computer system: The computer system serves two functions. First it must steer the antenna towards the non-GSO satellite and second it must collect the necessary data. To accomplish the first function requires orbital data of the non-GSO satellite (apogee altitude, perigee altitude, inclination, argument of perigee, and time of ascending node) being studied in order to predict where and when it will appear on the horizon. The satellite can then be tracked by predicting its location over time or by using a closed loop tracking system, which is part of the antenna subsystem. The second function of the computer is to take measurements at regular time intervals and record the measurement on a computer file along with other positional data such as the azimuth and elevation of the test antenna.

TABLE 1

Fixed parameters required for non-GSO satellite characterization tests

Parameter description	Symbol	Units	Value
Nominal non-GSO satellite parameters			
Transmit power into antenna	P_S	dBW	
Altitude of satellite	h_s	km	
Occupied bandwidth of downlink when modulated	B_{Soc}	MHz	
e.i.r.p.$_S - L_S$ (if constant)	e.i.r.p.$_s - L_s$	dB	
Difference (e.i.r.p.$_S - L_S$) (variable)(1)	Dif. (e.i.r.p.$_s - L_s$)	dB	
Downlink frequency	f_D	GHz	
Reference bandwidth	B_{ref}	Hz	
Test antenna coordinates			
Latitude	f_{test}	dd:mm:ss.s	
Longitude	l_{test}	ddd:mm:ss.s	
Antenna height (amsl)	h_{test}	m	
Test antenna characteristics			
Diameter	D_{test}	m	
Receive gain (at f_D)	$G_{RX\ test}$	dBi	
Noise temperature	$T_{A\ test}$	K	

TABLE 1 (*end*)

Parameter description	Symbol	Units	Value
Test-set parameters			
Antenna feed loss	L_F	dB	
Gain of LNA	G_L	dB	
LNA noise temperature	T_L	K	
Cable loss	L_c	dB	
Spectrum analyser data			
Make and model number			
Spectrum analyser settings during measurements			
Input attenuation		dB	
Reference level		dBm	
Amplitude resolution		dB/Div	
Centre frequency	F_C	GHz	
Frequency span	SPAN	kHz	
Resolution bandwidth	ResBW	kHz	
Video bandwidth	VBW	kHz	
Normalized noise-floor[(2)]	No_{SA}	dBm	

(1) In the case where sticky beams or an isoflux antenna is not used on the non-GSO satellite, the difference between the maximum on-axis e.i.r.p. – L_s and the minimum edge-of-beam e.i.r.p. – L_s for the intended service area should be given.

(2) Displayed noise-floor is that which is determined after application of correction factors for log amplifier, envelope detector and resolution-to-normalized bandwidth.

4 Conduct of the measurement test

Maximum power calculation: The first step in preparing the equipment is to ensure that the set-up is not overloaded by the maximum received power in the entire bandwidth of the LNA. By adjusting gains or adding attenuation along the receive path, it is possible to ensure that the spectrum analyser is not over driven. The expression below can be used to calculate the received signal level of the test-carrier being measured at the input to the spectrum analyser.

$$P_{RX\,test} = P_s + G_s - \left(L_s + L_{abs}\right) + G_{RX\,test} + G_{test-set} \tag{1}$$

where:

$P_{RX\,test}$: power of the received signal at the spectrum analyser (dBW)

P_s: power at the flange of the satellite antenna (dBW)

G_s: gain of the satellite antenna in the direction of the test station (dBi)

L_s: free space loss which is calculated using the equation:

$$L_s = 10 \log\left(\frac{4\pi d}{\lambda}\right)^2 \qquad \text{dB}$$

where:

d: distance from test antenna to satellite (m)

λ: wavelength of the signal (m)

L_{abs}: atmospheric absorption (dB)

$G_{RX\ test}$: gain of the test antenna including feed loss (measured at the output flange) (dBi)

$G_{test\text{-}set}$: gain of the test-set is calculated using the equation:

$$G_{test-set} = G_L - L_c \tag{2}$$

where:

G_L: gain of the LNA (dB)

L_c: loss of the cable (dB).

An example calculation of the maximum received power is given in Annex 2.

Minimum power calculation: The noise floor of the spectrum analyser and the test-set needs to be established to determine the dynamic range over which measurements can be made. The method for determining the practical minimum signal power that can be measured by the test set is explained in Annex 3.

e.i.r.p. calibration: The next step consists of calibrating the test set-up. Establishing the e.i.r.p. of the non-GSO satellite is most accurately done by measuring the energy level of a source with a known e.i.r.p. The measured level then serves as a reference power flux-density (pfd) which can be used to determine the e.i.r.p. of the non-GSO satellite. Various stable RF sources can be used as a calibration reference such as a GSO satellite beacon that is transmitted at a known e.i.r.p. or certain radio stars. If the equipment is not calibrated in this way, the measurements which are made will give information as to the relative gain of the non-GSO satellite in various directions but will not allow the exact power radiated in a given direction to be determined.

As part of the calibration process, it is important to measure the variation in receive gain of the test set across the frequency band which will be used for the tests. Since variations of 2 to 3 dB across the measurement band are not uncommon, it is important to know the extent of the gain variation between the frequency used to measure the reference e.i.r.p. level and the frequency at which the measurement will be taken.

Measurement of the non-GSO satellite signal: On each pass of a given non-GSO satellite, the tracking antenna follows the satellite and measurements are made of energy emanating from the satellite. At each measurement point, the azimuth and elevation of the antenna need to be recorded for later processing. Prior to each new measurement, the software will instruct the spectrum analyser to clear the trace. An average over three sweeps of the frequency span should be executed to minimize the effect of any short-term fluctuation in transmitted power level.

The time between data samples needs to be sufficiently short so as to capture the shape of the satellite antenna side lobes. The complexity of the non-GSO satellite transmit beam pattern and the altitude of the satellite are the two variables which will need to be considered when establishing the required time increment between measurements. The minimum set-up time required by the test-set is determined by the time required by the spectrum analyser to complete the three sweeps, make the measurement, pass the information to the computer and for the computer to store the information. The spectrum analyser minimum sweep time is a function of the span and resolution bandwidth and is available from the manufacturer's specifications.

When the non-GSO satellite passes through a zone close to the GSO arc, it will be necessary to take into account the potential interference contribution from GSO satellites. This may limit the amount of data that can be collected as the test antenna passes through a narrow region surrounding the GSO arc. An initial survey of the GSO arc prior to the commencement of tests may prove useful in finding a narrow, unused band over a significant portion of the GSO arc in which a continuous wave (CW) test carrier may be used.

Tests should be performed under clear-sky conditions to minimize the variation in measured signal levels in the course of a test. Preferably the test site location should have a horizon as close to a 0° elevation angle in all directions to allow the largest field of view possible.

If the non-GSO satellite travels on a repeating ground track, there will only be a finite set of measurement cuts of the antenna pattern. Testing from additional sites may be required in order to obtain sufficient data to characterize the non-GSO satellite's transmit e.i.r.p. pattern.

5 Processing of data collected

Non-GSO satellite with time invariant e.i.r.p. patterns: If the non-GSO satellite has an e.i.r.p. pattern that does not change with respect to the sub-satellite point then each pass by the test site constitutes a cut of the antenna pattern. With enough cuts it is possible to construct a plot of the satellite's e.i.r.p. with regards to its pitch and roll angle from nadir.

In order to obtain such a plot from the collected data, the orbital parameters of the non-GSO satellite along with the azimuth and elevation of the test antenna at each data point will be needed to determine:

d: distance to the non-GSO satellite from the test station

θ_1: pitch angle of the test station with regards to the nadir of the satellite

θ_2: roll angle of the test station with regards to the nadir of the satellite.

The following equation can be used to find the e.i.r.p. of the non-GSO satellite (e.i.r.p.$_s$) in the direction (θ_1, θ_2):

$$e.i.r.p._s = e.i.r.p._{ref} + 20 \log \left[\frac{d_{ref}}{d_{mes}} \right] + \Delta level + cal \tag{3}$$

where:

$e.i.r.p._{ref}$: e.i.r.p. of the reference source (dBW)

d_{ref}: distance from the earth station to the reference source (m)

d_{mes}: distance from the earth station to the satellite under measurement (m)

$\Delta level$: measured difference of the power between the level of the reference source and the non-GSO satellite (dB)

cal: gain variation between reference frequency and measured frequency (dB).

Once all the data points have been converted to e.i.r.p.$_s$, θ_1, and θ_2 a plot can be made of e.i.r.p.$_s$ versus θ_1 and θ_2. Software which draws contour levels on three dimensional data can be used to simplify the presentation of the information. Comparing these plots for the different satellites in the constellation will demonstrate if individual satellites are operating outside of their specified envelope.

Non-GSO satellite with time varying e.i.r.p. pattern: In cases where the non-GSO satellite e.i.r.p. pattern varies in time, it is not possible to measure an e.i.r.p. pattern. An example of such a type of pattern are sticky beams, where the boresight of the non-GSO satellite beam stays pointing at a given geographic location while that location is visible. As with a GSO satellite, the test station observing a non-GSO satellite with a sticky beam would always see the same point in the non-GSO satellite beam.

For non-GSO satellites with time varying e.i.r.p. patterns, the most that can be deduced is the equivalent pfd (epfd) at the test site for either one satellite or for the entire constellation if the non-GSO satellite is on a repeating ground track (see Note 1). This is accomplished by first finding the pfd at the test site for each data point by using the equation:

$$\Phi = e.i.r.p._{ref} - L_{abs-ref} - L_{s-ref} + G_{1\ \mathrm{m}^2} + \Delta level + cal \qquad (4)$$

where:

Φ: pfd at the site due to the non-GSO satellite in the reference bandwidth (B_{ref}) of the spectrum analyser (dB(W/(m^2 · B_{ref})))

$e.i.r.p._{ref}$: e.i.r.p. of the reference source (dBW)

$L_{abs\text{-}ref}$: atmospheric loss in the direction of the reference source (dB)

$L_{s\text{-}ref}$: free space loss in the direction of the reference source (dB)

$G_{1\ \mathrm{m}^2}$: gain of a 1 m^2 antenna (dBi)

cal: gain variation between reference frequency and measured frequency (dB).

Once the pfd, azimuth and elevation with respect to test antenna location are known, the off-axis mask of an antenna pointing towards a GSO satellite can be added to the data to get the epfd from a specific non-GSO satellite. By using all the data points gathered, it is possible to calculate the epfd statistics per non-GSO satellite. Comparing these statistics among different satellites in the constellation will identify any individual satellites that may be operating outside their performance envelope.

Furthermore, if the constellation operates with repeating ground tracks, it is possible to time shift corresponding to the non-GSO orbital parameters and power add the measurements from other non-GSO satellites in the constellation which are visible in the sky at that time in order to determine the epfd statistics of the constellation.

NOTE 1 – This assumes that the contribution due to other satellites is negligible for repeating ground track constellations. This assumption may not always hold true for all GSO/FSS antenna sizes or for all repeating ground-track constellations.

6 Factors affecting the accuracy of measurements

All measurements of the downlink signal made using a spectrum analyser will be limited in accuracy by the amplitude accuracy of the spectrum analyser itself, however there may be minor variations of the signal level itself that are not introduced by the measurement equipment. Many such variations in signal level may be minimized. The following assumptions are made when interpreting the data from measurements using this test procedure:

– Differences in the antenna noise temperature over a range of elevation angles have a small impact to the $(I+N)/N$ measurements. For increased accuracy, the impact of the estimated antenna noise temperature as a function of elevation angle can be taken into account.

– Uplink power control (UPC) is used on all uplinks to the non-GSO satellite and perfectly compensates dB-for-dB for rain fade on the uplink. For non-GSO satellite networks employing on-board processing (OBP), however, uplink propagation effects can be ignored.

– Transmit power level variations in the non-GSO earth stations and the non-GSO satellite are negligible. Again, if OBP is employed, the transmitter power level variation at the non-GSO earth station can be ignored.

– Earth station antenna tracking inaccuracies of the non-GSO satellite network and that of the test antenna are small on average and do not significantly affect the levels of interference being measured.

– Differences in atmospheric absorption over a range of elevation angles are small but do increase with increased frequency and with reduced elevation angle. This generalization can be made when the frequency is below 15 GHz and the elevation angle is above 10°. When the frequency is above 15 GHz or the elevation angle below 10°, however, atmospheric absorption should be accounted for to achieve desired accuracies.

– The sense of polarization of the interfering satellite antenna and tracking earth station antenna will affect the received non-GSO noise power density level received by the earth station. For an non-GSO satellite using circular polarization and a GSO earth station receiving vertically and/or horizontally linear-polarized waves, the receive signal will vary between 1 and 3 dB depending on the alignment of the antennas and the off-axis angle of the earth station antenna with respect to the centre of the main beam of the satellite. In practice, the coupling factor is likely to be considerably less than 3 dB except when the main beam of the non-GSO satellite is pointed directly at the tracking earth station antenna. The main beam gain of the non-GSO satellite antenna, however, is much more accurately known than are the sidelobe and thus can be accounted for in any post-processing of the data collected.

ANNEX 2

Example calculation of maximum received power at the input to the test-set LNA

The power received by an earth station terminal from a signal source a distance d away is given by the expression:

$$p_R = \frac{p_T \cdot g_T}{4\pi d^2} \cdot g_R \cdot \frac{\lambda^2}{4\pi} \qquad \text{W}/B_{ref} \text{ (Hz)} \tag{5}$$

where:

p_R: power received at the spectrum analyser input (W)

p_T: power at the flange of the non-GSO satellite antenna (W)

g_T: peak gain of the non-GSO satellite in the direction of the test site

d: distance between the test site and the non-GSO satellite (m)

g_R: gain of the receive earth station.

As:

$$\Phi = 10 \log\left(\frac{p_T \cdot g_T}{4\pi d^2}\right) \equiv \text{pfd} \qquad \text{dB(W/(m}^2 \cdot B_{ref} \text{ (Hz)))}$$

$$G_R = 10 \log(g_R) \equiv \text{gain of test antenna} \qquad \text{dBi}$$

$$G_{1\,\text{m}^2} = 10 \log\left(\frac{4\pi}{\lambda^2}\right) \equiv \text{gain of a 1 m}^2 \text{ antenna} \qquad \text{dBi}$$

Then equation (5) can be rewritten as follows:

$$P_R = \Phi + G_R - G_{1\,\text{m}^2} \qquad \text{dB(W/}B_{ref}\text{(Hz))} \tag{6}$$

Restating equation (6) as a function of test antenna diameter, D (m), and efficiency, η (%), the received power at the output of the test antenna is:

$$P_R = \Phi + 20 \log(D(m)) + 10 \log(\eta / 100) - 1.05 \qquad \text{dB(W/}B_{ref}\text{)} \tag{7}$$

If, for example, the maximum expected pfd in a 40 kHz reference bandwidth received by an 8 m test antenna with a 65% efficiency is –131 dB(W/m^2), and the test-set has a 1 dB feeder system loss with a 42 dB test-set gain, then the maximum power received in a 40 kHz reference bandwidth at the spectrum analyser input is:

$$P_R = -131 + 20 \log(8) + 10 \log(65/100) - 1.05 - 1 + 42 = -74.9 \text{ dB(W/40 kHz)}$$

If the total occupied bandwidth of the entire downlink spectrum was 2.0 GHz with a uniform pfd across the entire occupied bandwidth, the maximum total power into the spectrum analyser would be:

$$P_{R\ Total} = -74.9 \text{ dB(W/40 kHz)} + 10 \log(2 \times 10^9/40 \times 10^3) = -27.9 \text{ dBW} = 2.1 \text{ dBm}$$

This level of total power into the spectrum analyser should be within the tolerable maximum total power level of most spectrum analysers. In the event that the calculated maximum total power level exceeds the maximum safe input power level of the spectrum analyser, it may be necessary to insert some attenuation before the spectrum analyser input. Note that when the test antenna passes through the GSO, it will also encounter relatively high measured signal levels. Given that the difference between the path loss to the GSO satellite is typically greater than the amount by which the GSO satellite e.i.r.p. may exceed the non-GSO satellite e.i.r.p. in a given reference bandwidth, the calculated instantaneous power received into the spectrum analyser from a worst-case alignment with the non-GSO satellite typically represents the worst case. It would still be prudent, however, to calculate both cases to ensure that the test equipment will be protected.

ANNEX 3

Lowest measurement level

The lowest measurement level needs to be determined so as to establish a dynamic range in which accurate measurements can be made. The level is established by the thermal noise floor of the test set-up. In the following discussion, terms in uppercase are in dB and terms in lower case are in absolute terms.

To find the system performance, the equation modelling the RF link was first used:

$$P_{RX\ test} = P_s + G_s - L_s - L_{abs} + G_{RX\ test} + G_{test-set} \tag{8}$$

where:

$P_{RX\ test}$: power of the received signal (dBW)

P_s: power at the flange of the satellite antenna (dBW)

G_s: gain of the satellite antenna in the direction of the test station (dBi)

L_s: free space loss, which is calculated using the equation:

$$L_s = 10 \log \left(\frac{4\pi\, d}{\lambda} \right)^2 \quad \text{dB} \tag{9}$$

where:

d: distance from test antenna to satellite (m)

λ: wavelength of the RF signal (m)

L_{abs}: atmospheric absorption (dB)

$G_{RX\ test}$: gain of the test antenna including feed loss (measured at the output flange) (dBi)

$G_{test\text{-}set}$: gain of the test set is calculated using the equation:

$$G_{test-set} = G_L - L_c \qquad \text{dB}$$

where:

G_L: gain of the LNA (dB)

L_c: loss of the cable (dB).

A spectrum analyser displays a power level that includes both the wanted power and noise power in the bandwidth of interest. The ratio of the measured non-GSO interference level to the measured noise floor is more accurately represented by the term $(I + N)/N$ which shows the contribution of noise energy in the measured non-GSO interference level. For most cases where I >> N, then $I/N \cong (I + N)/N$, however this no longer applies for values of $(I + N)/N < 5$ dB. This value consists of and can be expressed by the following equation:

$$\left(\frac{I+N}{N}\right) = 10 \log\left(\frac{p_{RX\ test} + n_{test-set}}{n_{test-set}}\right) \tag{10}$$

where:

$(I + N)/N$: ratio of non-GSO interference power and noise-to-noise power measured on spectrum analyser (dB)

$p_{RX\ test}$: signal power at the input of the spectrum analyser (W)

$n_{test\text{-}set}$: noise power referenced to the input of the spectrum analyser (W).

The terms can be rearranged as follows:

$$P_{RX\ test} = 10 \log\left\{ n_{test-set} \left(10^{\frac{\left(\frac{I+N}{N}\right)}{10}} - 1 \right) \right\} \tag{11}$$

Now pfd (dB(W/m^2)) + antenna aperture (dB(m^2)) + $G_{test\text{-}set}$ = $P_{RX\ test}$ and antenna aperture = π (D^2_{test}/4) (efficiency).

So:

$$\Phi = P_{RX\ test} + 1.049 - 10 \log(\eta/100) - 20 \log D_{test} - G_{test-set} \tag{12}$$

where:

Φ: pfd (dB(W/m²) in ResBW (Hz))

η: efficiency of the test antenna (%)

D_{test}: diameter of the test antenna (m).

The resolution bandwidth (ResBW) of the spectrum analyser constitutes the reference bandwidth over which the pfd applies.

The noise of the entire test-set can be found by using:

$$n_{test\text{-}set} = n_{set\text{-}up} + n_{sa}$$

If a spectrum analyser is selected such that the noise contribution of the spectrum analyser (N_{sa}) is significantly less than the noise level of the test set-up ($N_{set\text{-}up}$) then:

$$N_{test\text{-}set} \cong N_{set\text{-}up}$$

To find $n_{set\text{-}up}$:

$$t_{set-up} = \left(\frac{t_A}{l_f} + \left(\frac{l_f - 1}{l_f} \right) t_0 + t_L \right) \left(\frac{g_L}{l_c} \right) + \left(\frac{l_c - 1}{l_c} \right) t_0 \qquad (13)$$

where:

t_A: antenna noise temperature (K)

l_f: antenna feed loss

t_0: temperature of the medium (K)

t_L: LNA temperature (K)

l_c: cable loss

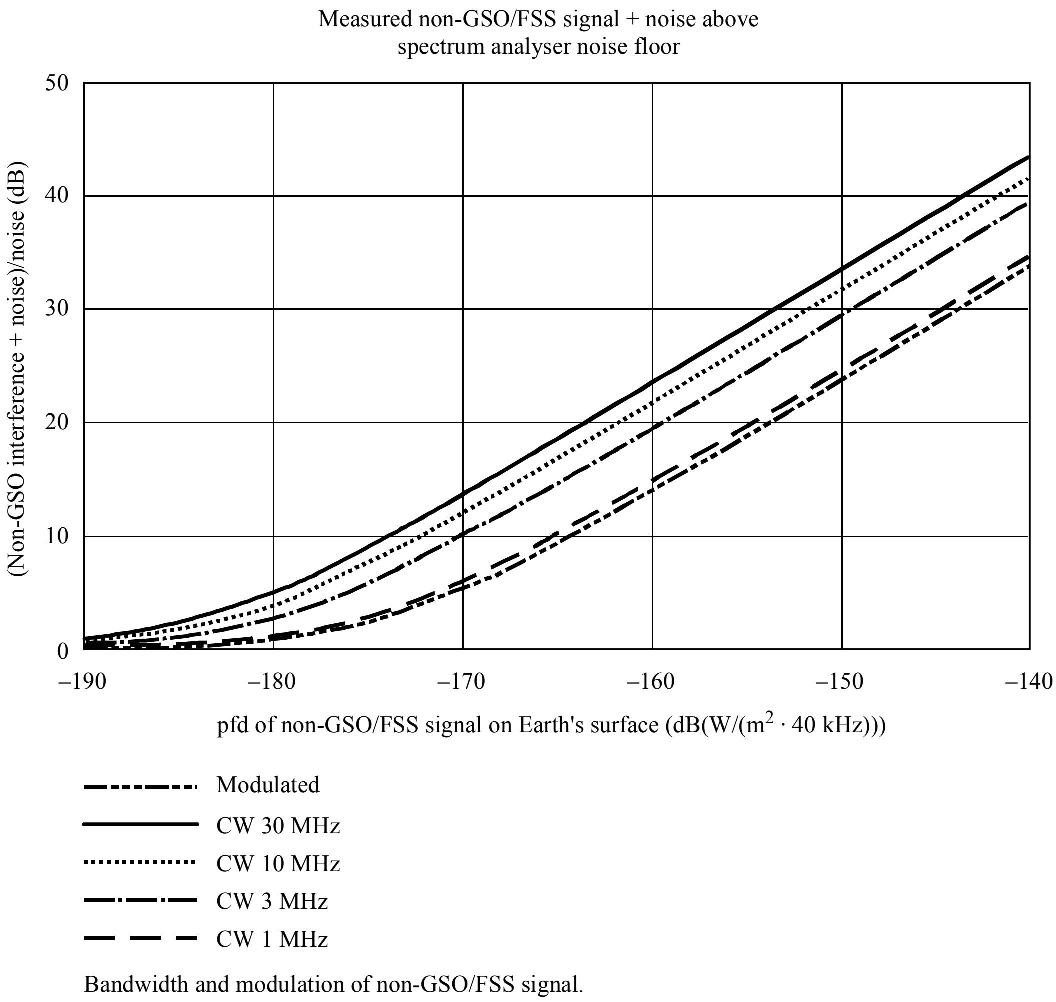
g_L: gain of the LNA.

Substituting the result from equation (13) and the other parameters of the test set-up into equation (12) gives a pfd below which results are of decreasing accuracy.

In order to obtain larger $(I + N)/N$ values when measuring the downlink interfering signal level from the non-GSO satellite, it is desirable to be able to use an unmodulated CW carrier as a test signal. Since nearly the entire power lies within a very narrow band, improvements in the $(I + N)/N$ can be obtained by lowering the resolution bandwidth on the spectrum analyser. When the signal being measured is digitally modulated, however, only the ratio of the power received in the ResBW to the total noise in the RBW determines the ratio of $(I + N)/N$ and thus no improvement in $(I + N)/N$ can be achieved by lowering the ResBW. Figure 2 shows the $(I + N)/N$ that could be measured for both an unmodulated carrier and a carrier with digital modulation. Given the higher total power in wider band interfering carriers (10 and 30 MHz), a CW test carrier need not be transmitted at the total power of the modulated carrier to achieve the needed improvements in $(I + N)/N$.

FIGURE 2

Measured (*I* + *N*)/*N* of non-GSO FSS signal levels on test-set



Note 1 – Total power of each non-GSO/FSS signal is backed-off by 6 dB and 3 dB for the 30 MHz and 10 MHz carriers respectively from the total power of the modulated signal.

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NOTE 1 – The above is an illustrative example of the improvement achieved through the use of a smaller ResBW under the conditions defined in Table 2. The actual dynamic range of a specific test site will vary depending on the site characteristics. The example only displays the impact of thermal noise without considering other external sources of interference.

TABLE 2

Example of noise temperature calculation

Test-set data

T_{ANT}:	25 K
L_F:	1 dB
T_{LNA}:	100 K
G_{LNA}:	45 dB
L_c:	3 dB
$G_{test\text{-}set}$:	42 dB

Test antenna data

Antenna diameter:	8 m
Aperture efficiency:	65%
Incident pfd:	–160.0 dB(W/(m^2 · 40 kHz))

At input to LNA

B_{ref}:	40 kHz
I_{test}:	–145.86 dB(W/B_{ref})
T_{SYS}:	179.5 K
$I/N_{thermal}$:	14.18 dB

At input to receiver

$C_{RX\ I/P}$:	–103.9 dB(W/B_{ref})
T_{SA} (input terminated):	341 193 K
T_{SYS}':	2 845 000 K
T_{SA}' (test-set at I/P):	3 186 000 K
Resultant noise-floor:	–125.3 dBm/ResBW
Increase in noise-floor:	9.70 dB
$I/N_{thermal}$:	13.69 dB
Reduction in I/N:	0.49 dB

Spectrum analyser data

Displayed noise-floor:	–135.0 dBm/ResBW
Actual noise-floor:	–133.29 dBm/ResBW
ResBW:	10 Hz
Noise figure:	30.71 dB