Dual Operation of TerraSAR-X and TanDEM-X with One Ground Antenna

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Usually, in order to control a satellite, a ground antenna is required. In this paper we study the aspects of simultaneous operation of several satellites at the same time with one ground antenna, thus increasing the efficiency. The upgrade, required for such capacity of the ground station antenna system, depends on the mission specifications and the chosen concept for communicating with the satellites.

German Aerospace Centre has launched TerraSAR-X satellite (2007) and TanDEM-X satellite (2010). The unique situation is that the distance between both satellites is only around 500 meters for an orbit of 514 km which in return gives us an opportunity to use one ground antenna's 3dB-beam for transmission of telecommands, reception of telemetry and tracking for both satellites.

The goal of this paper is to show the installation, configuration and operation of the satellites when only one ground antenna is active. A practical example shall be described and the results will be given in terms of signal processing and M&C system design. Moreover, the operation for one and two satellites cases will be compared, in order to make an objective conclusion about the reasonable upgrade of the ground antenna. The paper shall conclude with the analysis of the advantages and disadvantages as well as with statement of future works.

This paper is intended to be used as a guide for other organizations to identify their requirements for ground antennas, which could be used to support several satellites simultaneously.

Nomenclature

d = distance between TerraSAR-X and TanDEM-X
l_1 = altitude to TerraSAR-X
l_2 = altitude to TanDEM-X
γ = minimum half-power beamwidth

I. Introduction

THE German Aerospace Centre (DLR) has an earth observation mission, where two satellites (TerraSAR-X and TanDEM-X) are in a very short distance to each other. This option gives an opportunity to provide TT&C with one of the antennas in the Weilheim ground station. For these purposes, two 15-meter S-band antennas have been normally used. Due to some frequency specifications of the satellites, some adjustments in antenna's hardware construction had to be done. Furthermore, the in-house developed M&C System for the Multi Mission Operation of the station had to be modified.

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II. TerraSAR-X and TanDEM-X Satellites

A. Overview

TerraSAR-X (Fig. 1) is Germany's first national remote sensing satellite that has been implemented in a public-private partnership between the German Aerospace Centre and EADS Astrium GmbH. It provides high-quality topographic information for scientific and commercial applications. The name TerraSAR-X consists of three parts:

- Terra (latin) means Earth;
- SAR – Synthetic Aperture Radar. Cross-range resolution obtained from Doppler frequency, along with range resolution, is the basis for SAR. SAR produces an image of a scene that is similar, but not identical, to an optical photograph. One should not expect the image seen by radar "eyes" to be the same as that observed by optical eyes. Each provides different information;
- X – frequency band, in which radar is functioning.

At the same time it was designed to satisfy the steadily growing demand of the private sector for remote sensing data

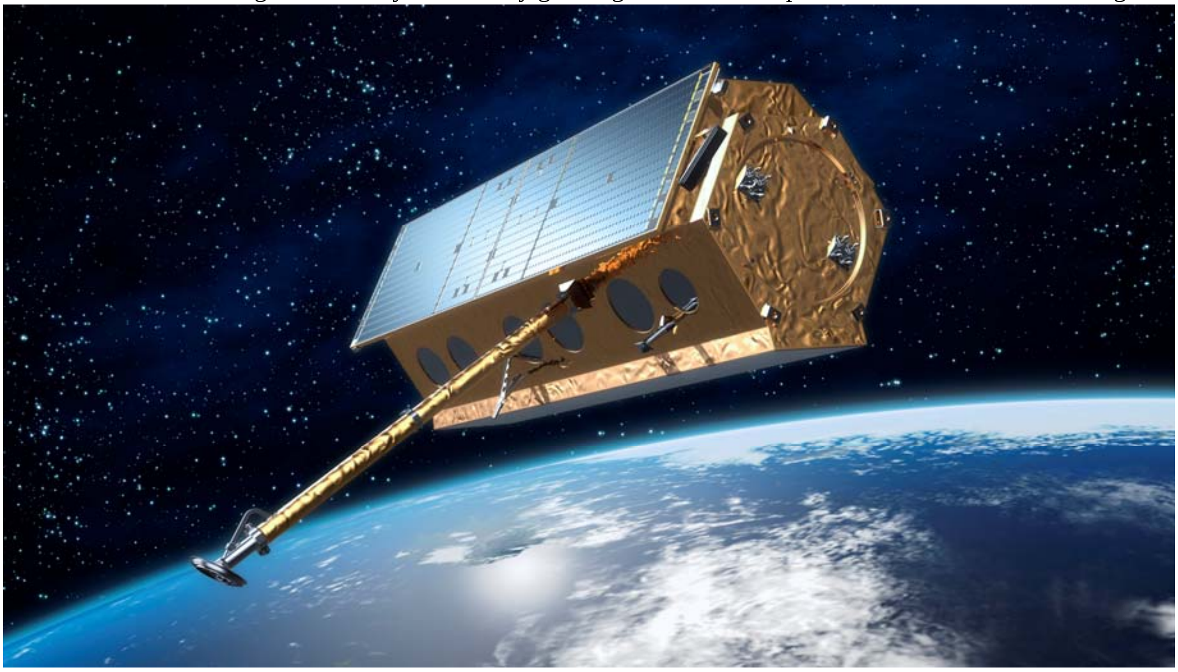

Figure 1. TerraSAR-X remote sensing satellite.

in the commercial market.

TanDEM-X (TerraSAR-X-Add-on for Digital Elevation Measurements) is a twin satellite for TerraSAR-X. TanDEM-X flies alongside to TerraSAR-X at a distance of around 500 meter. The addition of TanDEM-X as a second "eye" could record a three dimensional elevation model of the entire Earth. Both satellites are in Low Earth Orbit (LEO) and its altidute is equal to 514 km.

B. RF Parameters

S-Band frequency is used for tracking, telemetry and telecommand (TTC). Table 1 shows the details of radio frequency parameters for uplink and downlink:

It is obvious that there is no frequency overlapping between carrier frequency and its bandwidths. It means that a

	TerraSAR-X	**TanDEM-X**
Uplink (TC) Carrier frequency	2093,5 MHz	2087,5 MHz
Downlink (TM) Carrier frequency	2280 MHz	2268 MHz

Table 1. Uplink and downlink frequency for TerraSAR-X and TanDEM-X.

design of a 15-meter antenna should be changed to transmit and to receive signals simultaneously on two different frequencies for uplink and downlink.

III. 15-meter S-band Antenna

A. Antenna System

Normally the antenna is used for telemetry reception, telecommand transmission, and orbital measurements. The 15-meter S-band antenna's system is capable of monopulse autotrack operation, with computer control and manual capability as back-up. The block diagram of new antenna's design is shown in Fig. 2. Before discussing the new capabilities of the antenna, there should be a short introduction of basic functions of antenna.

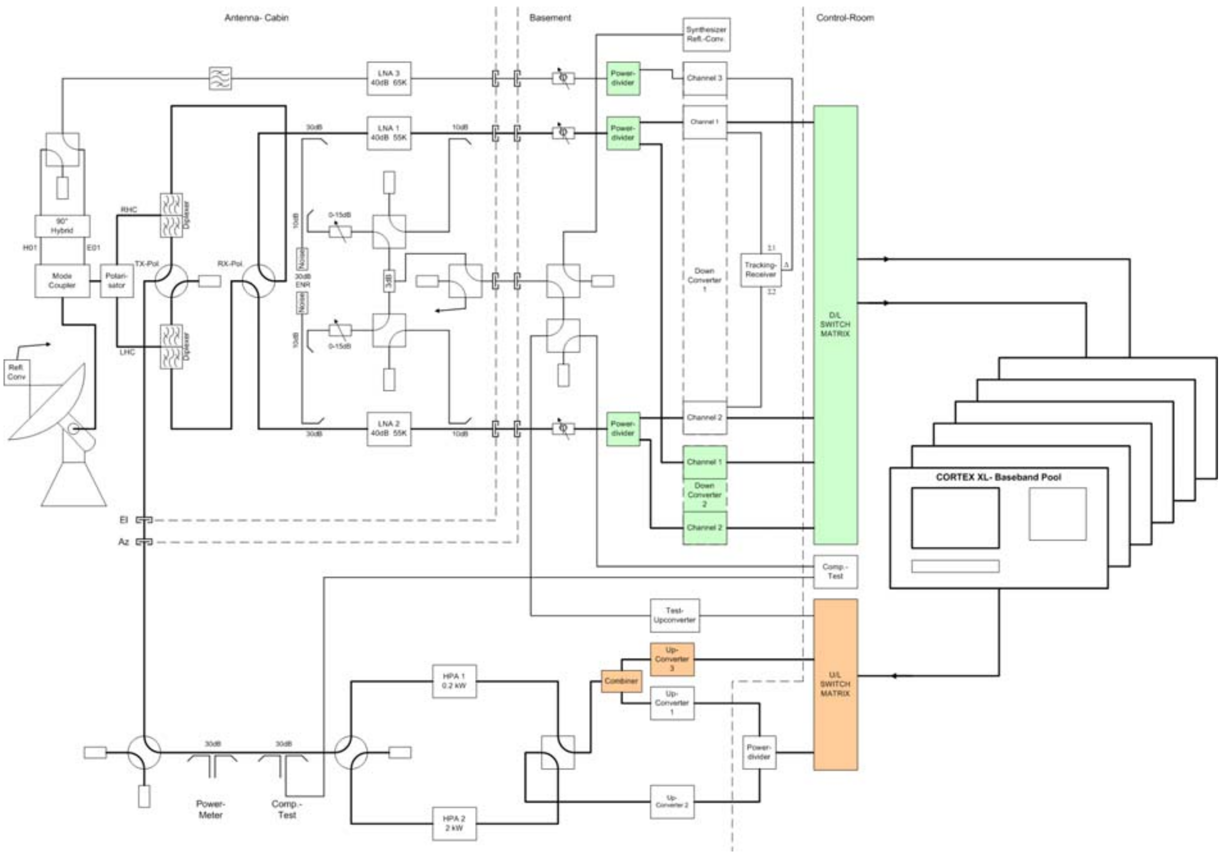

Figure 2. The new block diagram of the 15-meter S-Band antenna.

B. Polarization Capability

The feed network is capable of receiving and transmitting circular polarized signals by means of a polarizer integrated into the feed assembly. The transmit polarizer can be switched to Right Hand Circular Polarization (RHCP) or Left Hand Circular Polarization (LHCP) exclusively. The polarizer provides two receive ports allowing for simultaneous reception of RHCP and LHCP signals. These signals are combined in polarization diversity combiner of the TT&C baseband equipment in order to achieve the optimum Signal-to-Noise-Ratio (SNR) performance.

C. Autotracking

A mode coupler inserted between feed horn and polarizer generates the autotracking error signals necessary for autotrack operation of the antenna. The autotrack signal combining network is configured for circular polarization (RHCP/LHCP).

D. Receive System

These are the parameters for receive system capabilities, which are defined by feed system (Table 2):

Frequency range	2200—2300 MHz
Polarization	RHCP and LHCP
Antenna gain	43,3 dBi @ 2250 MHz
Half-power beamwidth	0,62°

Table 2. Ground antenna receive system.

E. Transmit System

These are the parameters for transmit system capabilities, which are defined by feed system (Table 3):

Frequency range	2025—2120 MHz
Polarization	RHCP or LHCP
Antenna gain	59—79 dBWi @ 2075 MHz
Half-power beamwidth	0,66°

Table 2. Ground antenna transmit system.

F. Low Noise Amplifier (LNA)

The LNAs are placed on the antenna mounts, as near to the feed as possible, to minimize system noise temperature.

G. Downconverter

A 3-channel downconverter with a frequency synthesizer common to all the three channels is used to convert the two cross-polarized sum channels (RHCP and LHCP) in order to maintain phase relationship between sum and error channels. The downconverter reduces the signal frequency in order to limit transmission losses and provides a frequency range compatibility with receivers.

H. Tracking Receiver

After amplification and downconvertion the two sum signals and the tracking signal are input to the three channel tracking receiver for detection of the azimuth and elevation tracking error signals. These error signals are then fed to the Antenna Control Unit (ACU) in order to eliminate the tracking error in autotracking mode. The tracking receiver automatically selects the best of the two sum signals as a reference for detection.

I. Upconverters

The upconverters translates an intermediate frequency (IF), which is equal to 70 MHz, to the required S-band output frequency.

J. High Power Amplifier (HPA)

The transmit system is equipted with two redundant high power amplifiers, places in the antenna basement:

- One 200 W Traveling Wave Tube Amplifier (TWTA);
- One 2kW Klystron Amplifier.

The TWTA is a wide band device which covers the whole transmit band without tuning. The Klystron amplifier's remotely controlled step motor tuning assembly allows frequency tuning to any frequency within the transmit band 2025 to 2120 in less than 5 minutes.

K. Antenna Design

As it was mentioned before, both satellites have two different carrier frequencies which do not overlap each other, whether it is for TC or TM (Fig. 3). On Fig. 1 the new RF hardware is noticed with different colours (green for reception and orange for transmission). Now the antenna has the capability to transmit and to receive the signals for two carrier frequencies simultaneously (Ref. 1).

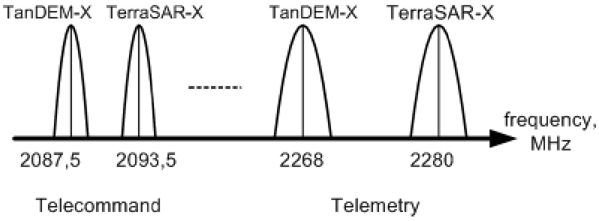

Figure 3. Spectrum for TC and TM.

Normally the baseband equipment allows to operate only with one satellite. It means that an additional device is necessary in order to work with the second satellite simultaneously. Now, each device will be responsible for the communication with every satellite separately.

After the telecommand frames for each satellite were generated by baseband equipment, the IF signals feed into the uplink switch matrix. As a matter of fact, an extra place in uplink switch matrix is provided to get connection for the second baseband device to antenna's RF equipment. Now both IF telecommand signals have to be upconverted to appropriate frequency that are specified in Table 1 for each satellite. Having both signals in S-Band separately, we should combine them into one. Using power combiner, our new signal will be with two carriers which do not overlap in frequency domain and decreased by 3 dB. Now the combined signal (Fig. 4) can be amplified by HPA and transmitted to satellites.

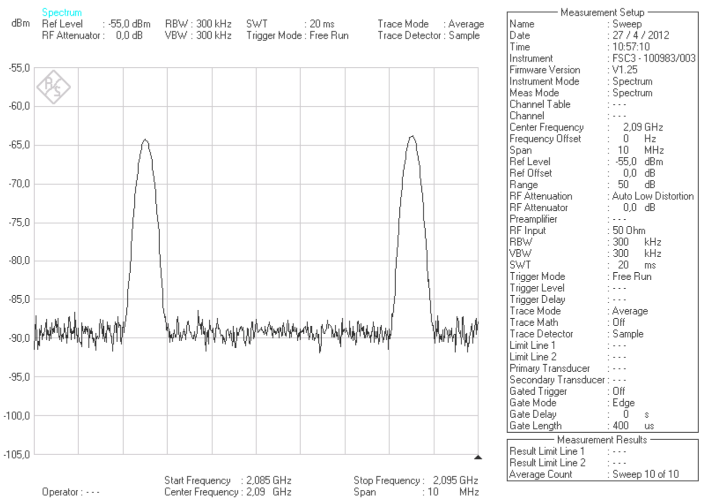

Figure 4. Uplink signal for TC.

The telemetry signal from both satellites consists of two carriers. After passing through the feed, polarizator and LNAs, it is necessary to split the received signals (Fig. 5a) on two equal replicas with power dividers. Each replica is decreased by 3 dB (due to power dividers) and is fed to Downconverter1 and Downconverter2. Downconveter will take only one carrier frequency and its bandwidth (Fig. 5b) that is adjusted to one of the satellites. It means that if the Downconverter1 takes the TM signal of TerraSAR-X, then the Downconverter2 takes the TM signal of TanDEM-X. As both signals are converted to IF, it could be transmitted to downlink switch matrix which would connect to corresponded baseband equipment to demodulate, to decode and to correct the errors (Ref. 1).

L. Coverage Zone of 15-Meter Antenna

Now let's prove that 15-meter S-band antenna is capable to cover the area of two satellites. This coverage zone exists only in the area of half-power (3dB) beamwidth of the antenna. This is shown in Fig. 6. Knowing all the parameters of satellites orbit, it is possible to calculate the minimum beamwidth of the 15-meter antenna. To shorten all the calculation, an extreme case will be taken into account, when satellites are in zenith (elevation of antenna is equal to 90°). If this condition is fulfilled, then any other position of satellites will satisfy our requirements due to a slant range, which increases our coverage zone for a lower elevation angle of antenna (Ref. 1).

The calculation can be done with the help of the following formula:

$$\gamma = \arccos\left[(l_1^2 + l_2^2 - d^2)/2 \cdot l_1 \cdot l_2)\right] \qquad (1)$$

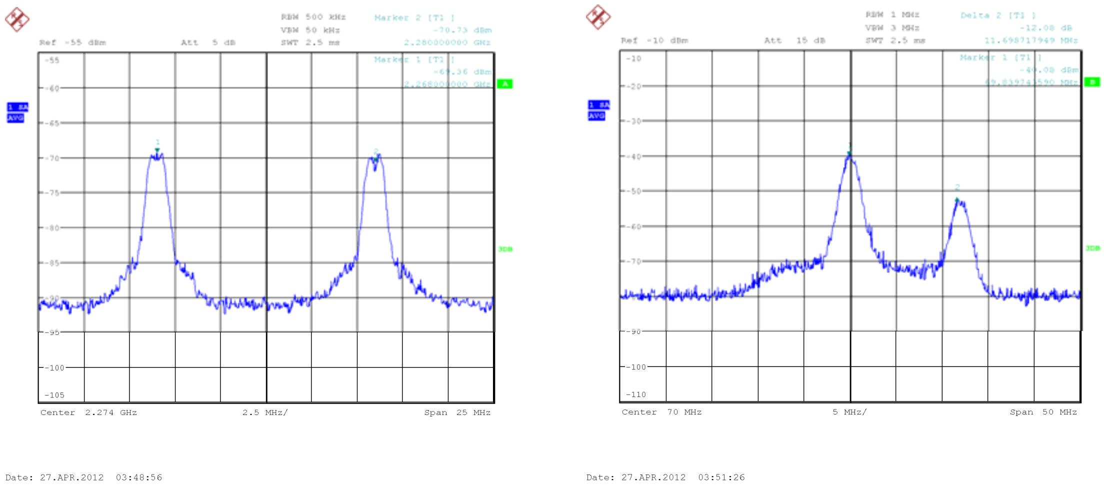

Figure 5. a – Downlink signal for TM (left); b – Downlink signal after downconverter (right)

where d – distance between the satellites, l_1 and l_2 are the altitudes from ground antenna to satellites, γ – minimum half-power beamwidth. Calculating equation (1), γ is equal to 0,0557°. Comparing it with half-power beamwidth of ground antenna for uplink and downlink which are 0,66° and 0,62° respectively, a conclusion is made that the 15-meter S-band antenna is valid for dual operation for TerraSAR-X and TanDEM-X satellites.

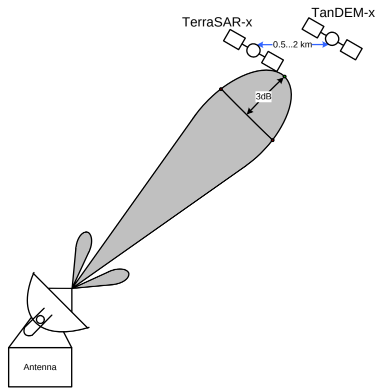

Figure 6. Antenna's beamwidth

IV. M&C System Adaptations

The in-house developed M&C System for the Multi-Mission Operation is designed to support one satellite pass with one ground antenna. Due to the fact that it is possible to handle TerraSAR-X and TanDEM-X satellites in one pass with one antenna, the system has to be adapted. The concept of the M&C System is to give to the operator the same view and possibilities of each antenna for every mission. This covers the representation of the antenna hardware in the graphical user interface (GUI) as well as the pool and the order of workflows which are used to control the individual antenna to support the pass.

Since the system is mission based, the first step of the system adaption was to create a new mission for the dual support. In this mission the two individual missions, which were available before, had to be merged. The two main points which had to be adapted were:

1) Configuration of the antenna hardware
2) Additional control possibilities for the pass

From the design of the antenna a requirement was stipulated. One of the two satellites had to be master and the other one – slave. An example for that is the predict file which is loaded in the ACU. It can be either for TerraSAR-

X or TanDEM-X. There is no own predict file for the dual support mission because it is not needed since the distance between the two satellites is very small. Weilheim Ground Station is the prime station for the TanDEM-X and backup station for the TerraSAR-X operation. This setup gives the first idea for the configuration of the antenna.

The setup before the pass had to be split up into two parts. The usual configuration workflow for a pass takes all devices which are available (e.g. not in maintenance) and configures them for the specific mission. To run a second configuration workflow after the first one would mean that the configuration in all devices would be overwritten by the second one. To solve this problem a state for each device in the M&C System was defined which ensures that the configuration workflow doesn't touch it. After the first setup the devices which are already configured are put into this state and the second setup is run. An example for that is the different configuration for Up- and Downconverters. Downconverter 1 and Upconverter 1 have to be configured for TanDEM-X and Downconverter 2 and Upconverter 3 for TerraSAR-X. Firstly, the configuration for TanDEM-X is done, it means that all devices are configured for the TanDEM-X mission. Afterwards, Downconverter 1 and Upconverter 1 are put into the new special state and the setup for TerraSAR-X is run which configures only Downconverter 2 and Upconverter 3.

The second change compared to a normal mission is the additional control for the pass. Especially the control of the individual uplink carriers has to be provided to the operator. This includes the start of the uplink and the stop of the uplink, see table below.

Start Uplink	Start Dual Uplink
	Start TanDEM-X Uplink
	Start TerraSAR-X Uplink
Stop Uplink	Stop Dual Uplink
	Stop TanDEM-X Uplink
	Stop TerraSAR-X Uplink

The workflows on the right side replace the two normal workflows for standard missions. With the new workflows the operator has the full control of the individual uplinks.

- Start/Stop Dual Uplink:
  - Enables or disables the uplink for both satellites at the same time.
- Start/Stop TanDEM-X or TerraSAR-X Uplink:
  - Enables or disables the uplink for the TanDEM-X or TerraSAR-X satellite. This is done only at the mission specific devices, that was explained above.

These changes have no influence on the operators view on the system. For them the steps which they have to do for the pass are the same. They execute the same workflows as before. The M&C System takes care of the special setup in scripts which lie underneath the workflows and therefore the operator doesn't see them.

V. Operations Benefits

The operational benefits with the Dual Operation of TerraSAR-X and TanDEM-X with one Ground Antenna are obvious and covered by the two following main points:

1) In the past the operator had to prepare two antennas at the same time for a TerraSAR-X and TanDEM-X pass. That is on one hand twice more work as with the Dual Operation Concept and on the other hand it doubles the sources for errors. These can be errors which come from a miss-configuration by the operator or errors which can occur at devices in one of the antennas.

2) The efficiency of the station antennas increases. It means more satellites can be supported with the same amount of antennas.

VI. Conclusion

From economic point of view comparable missions in which two or even more satellites that fly very close to each other should have a similar setup as TerraSAR-X and TanDEM-X if the frequency plan is similar, where no overlap between carriers is taking place. This method is very simple because it does not require any complex solutions, but it asks high investments in hardware. DLR is able to support such missions easily and with less preparation time like for these two satellites since the station / antenna hardware and the M&C System software are prepared for that.

For future missions with higher amount of satellites a more advanced solution has to be found. The work should be done in area of spectral spreading based on CDMA, where more users can utilize the same frequency band without disturbing the neighbouring user channel. Meanwhile, this leads to a more complicated design of satellites and ground antennas.

Appendix A
Acronym List

ACU	Antenna Control Unit
Az	Azimuth
D/L	Downlink
dB	Decibel
EADS	European Aeronautic Defence and Space Company
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Centre)
El	Elevation
GHz	Giga Hertz
GmbH	Gesellschaft mit beschränkter Haftung
GUI	Graphical User Interface
HPA	High Power Amplifier
IF	Intermediate Frequency
kW	Kilo Watt
LEO	Low Earth Orbit
LHCP	Left Hand Circular Polarization
LNA	Low Noise Amplifier
M&C	Monitoring and Control
MHz	Mega Hertz
ms	Millisecond
RF	Radio Frequency
RHCP	Right Hand Circular Polarization
SAR	Synthetic Aperture Radar
SNR	Signal to Noise Ratio
TC	Telecommand
TM	Telemetry
TTC	Tracking, Telemetry and Telecommand
TWTA	Travelling Wave Tube Amplifier
U/L	Uplink
W	Watt

Appendix B

Acknowledgments

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References

[1]Dikanskis, D., Haeusler, M., and Wiedemann, K., “Simultaneous TT&C of TerraSAR-X and TanDEM-X Satellites with One Ground Antenna,” *Test and Telemetry Conference*, Toulouse, France, 2011.