Receiving BEIDOU, GALILEO and GPS signals with MATLAB® and R&S®IQR, R&S®TSMW
Application Note

Products:

- R&S®TSMW
- R&S®IQR
- R&S®SMBV100A

Satellite Navigation became quite common during the recent years. In addition to the established U:S: GPS system, China has develloped its own navigation system called BEIDOU. Since BEIDOU receivers are not yet wide spread on the market, this MATLAB based application can be used to analyze and process BEIDOU signals. The free application enables and demonstrates remote operation of Rohde & Schwarz instruments using SCPI commands and attribute based drivers directly out of MATLAB scripts and functions.

BEIDOU SW Receiver Matlab — 1MA203_0e

Andreas Reil - 1MA203_0e

Application Note

ROHDE&SCHWARZ

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1 Preface

Global Navigation Satellite Systems (GNSS) became quite common during the past decade. With switching off Selective Availability (SA) in May 2000, civil accuracy increased from about 100m to 10m. This led to GPS becoming an interesting technology for civil navigation.

With the rise of smartphones, pedestrian navigation became popular. Using ground based augmentation systems, the accuracy can be improved to a few centimeters.

Precise positioning is of high interest for military applications and other countries have developed their own navigation systems: Those systems are similar to the GPS specifications and enable multiple GNSS receivers for enhanced precision. If the European and the Chinese deploy their navigation satellites according to the time schedule, there will be more than 90 operating navigation satellites available in space within a few years.

This application note briefly explains how those satellite navigation systems work in general and where they differ in detail. An existing GPS software receiver [2] is modified to work with BEIDOU and GALILEO signals.

Rohde & Schwarz signal generators able to simulate navigation systems with up to 24 satellites. Those generators can be used for quick receiver testing, hardware in the loop applications and advanced simulation tasks. GPS positioning can be quickly performed by putting a smartphone near to the SMBV signal output. In case of Beidou signals, most smartphones and receivers currently on the market aren't of any use since they are not capable of processing Beidou data.

The provided MATLAB application is able to record and analyze GNSS data. It directly remote controls all necessary instruments: a Rohde & Schwarz Universal Radio Network Analyzer (TSMW) is used as RF Front-end, connected to an I/Q Recorder (IQR). The setup is shown in figure 1-1.With an additional active GPS antenna, it is possible to analyze real-world GNSS signals received from space.

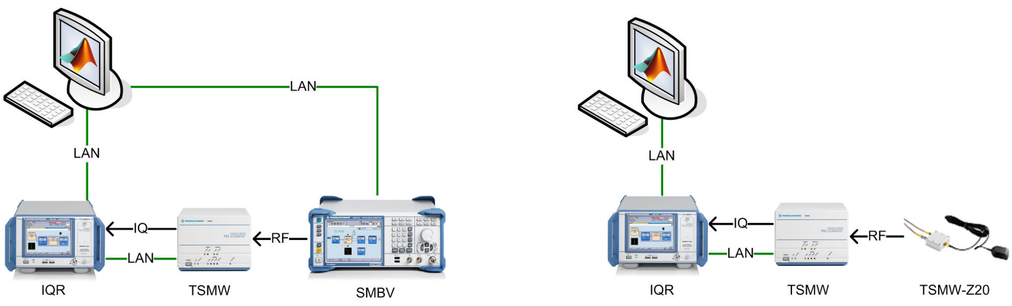

Fig. 1-1: Exemplary setup with GNSS simulation (left) and live capture (right).

Furthermore, several ways of controlling Rohde & Schwarz instruments directly out of MATLAB scripts and functions are shown within this application: The signal is generated using a SMBV controlled with SCPI commands and recorded using an IQR and TSMW operated using VXIplug&play drivers. The complete MATLAB code is supplied together with the application note.

The received navigation information is provided in a way that positioning is made possible. Data processing and channel coding is implemented in MATLAB. The presented receiver is based on a modified version of the GPS receiver introduced in [2]. It is able to process the ephemeris data contained in the BEIDOU and GPS signal. GALILEO signals can be acquired.

The following abbreviations are used in this Application Note for Rohde & Schwarz test equipment:

- The R&S®SMBV100A vector signal generator is referred to as the SMBV.
- The R&S®TSMW Universal Radio Network Analyzer is referred to as TSMW.
- The R&S®IQR I/Q Data Recorder is referred to as IQR.
- The R&S®FSQ signal analyzer is referred to as the FSQ.
- The R&S®FSV spectrum analyzer is referred to as the FSV.
- The R&S®FSW spectrum analyzer is referred to as the FSW.
- The R&S®FSU spectrum analyzer is referred to as the FSU.
- FSV FSQ, FSV, FSW and FSU are referred to as FSx.

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2 Navigation with Satellites

The following subchapters describe the principles of satellite navigation. The more interested reader is referred to [1].

2.1 Satellite Orbits

All modern satellite positioning systems are based on the measurement of the distances between the satellites and the receiver. Since absolute measurements of the signal runtime would require perfectly synchronized clocks, only so-called pseudo-range measurements are performed by the receiver. With the help of four pseudo-ranges, the absolute position of the receiver can be calculated. To measure the pseudo ranges, the satellites' positions need to be accurately known: The satellite orbits can be described using six Keplerian parameters (see left of figure 2-1) contained in the ephemeris data. Detailed information on the BEIDOU ephemeris data can be found in chapter 2.3, "Navigation Message", on page 8.

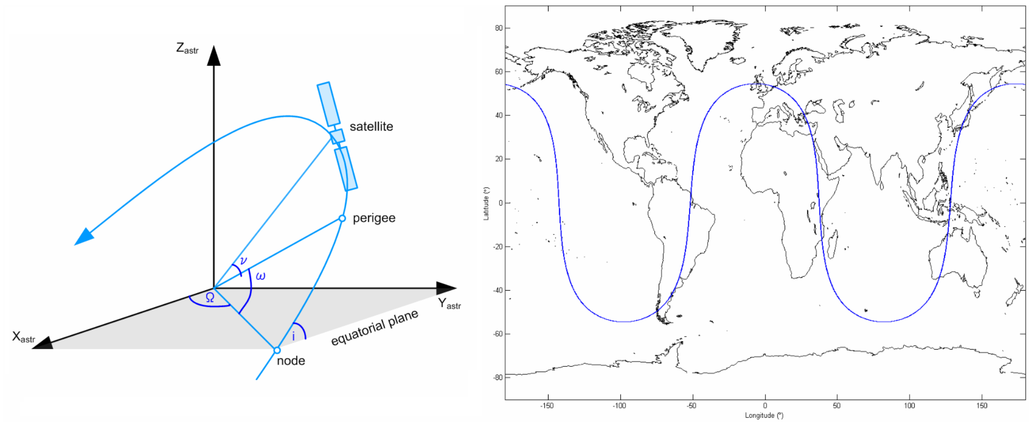


Fig. 2-1: Medium Earth Orbit (MEO) satellite and its ground track plotted with MATLAB's orbital mechanics library [3].

Since the satellite orbit changes over the time, a few more variables need to be transferred within each satellite's ephemeris to allow more precise position estimations. The more precise a satellite's orbit can be calculated, the more accurate the receiver's position will get.

All GPS and the majority of BEIDOU and GALILEO satellites are located in Medium Earth Orbits (MEO) at about 20,000 km above sea level. The corresponding ground track is illustrated on the right side of figure 2-1. The number of satellites and their exact orbits are chosen in such a way that in the entire system at least four satellites are visible at any time from any point on the earth's surface.

2.2 RF signals

The allocation of the L-Band frequencies by the four major GNSS is shown in figure 2-2: The lower L-Band is occupied by military navigation with non-public spreading codes and the upper L-Band is aimed at commercial receivers.

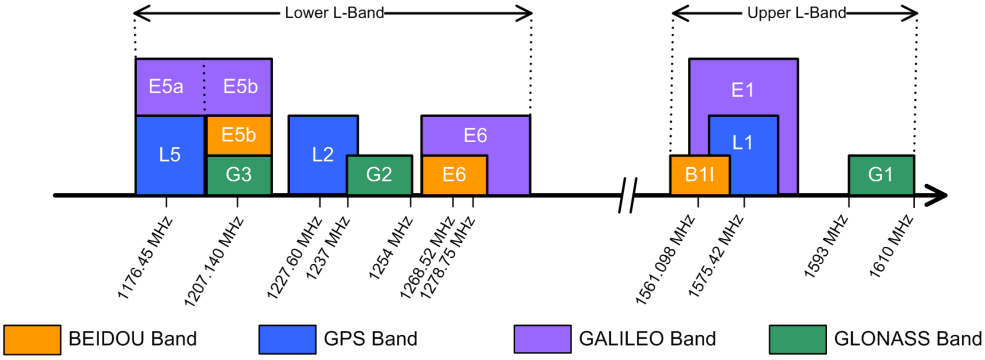


Fig. 2-2: BEIDOU, GALILEO, GLONASS and GPS frequency bands.

This application note does not treat GLONASS and focuses on the signals transmitted within the upper L-band. This is caused by several reasons:

- BEIDOU, GALILEO and GPS make use of code division multiple access (CDMA) to distinguish between the satellites. GLONASS uses frequency division multiple access (FDMA) and would therefore require different signal processing.
- Signals of all three CDMA based GNSS can be received using the same hardware setup.
- The upper L-band signals are used for public navigation and are therefore well documented and not encrypted.

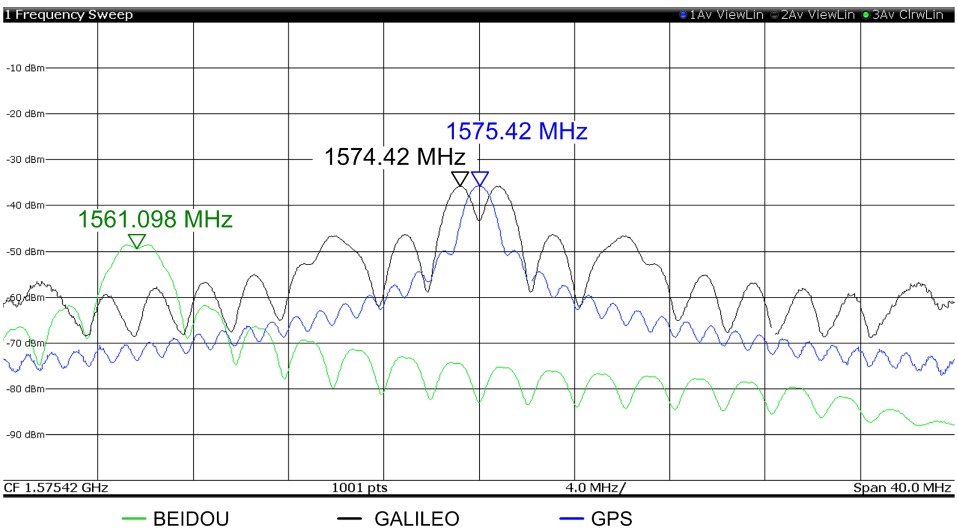


Fig. 2-3: Spectrum of GNSS signals generated with the SMBV100A.

Most GPS antennas do not use precise filters and hence able to receive at least some of the signal transmitted by BEIDOU satellites. The spectral power received by the

GPS RF Recording Kit R&S TSMW-Z20 is shown in figure 2-3. For better visualization, the signals where generated using a SMBV. The attenuation of this GPS antenna at the BEIDOU center frequency is approximately 10dB compared to GPS.

The data streams can be separated by multiplication with a perfectly aligned replica of the spreading code. These codes possess characteristics comparable to randomly chosen sequences and thus are named Pseudo Random Noise (PRN) codes. They can be created using linear shift registers with feedback implemented in MATLAB.

In figure 2-3, the BEIDOU carrier is situated at 1561.098 MHz. The spectrum shows that both BEIDOU and GPS (f_0 = 1575.42 MHz) use code division multiple access (CDMA), whereas the main lobes of the GALILEO signal are shifted 1 MHz (left and right). This can be achieved using Binary Offset Carrier (BOC) modulation: A BOC signal is composed of a sine carrier modulated with the product of the PRN sequence and a digital subcarrier. This way, the spectrum is split into two symmetrical components (see [2] chapter 3.2.3 "Binary Offset Carrier Modulation").

An overview of the key facts of the four main GNSS is given in table 2-1.

Table 2-1: Comparison of up in space GNSS

	BEIDOU	**GPS**	**GALILEO**	**GLONASS**
Public Frequency	1561.098 MHz	1575.42 MHz	1575.42 MHz	1593-1610 MHz
Modulation Type	QPSK (I-axis for open signal)	BPSK	BOC(1,1)	BPSK
Multiple Access	CDMA	CDMA	CDMA	*FDMA*
Spreading Code length	2047 chips	1023 chips	4092 chips	--
Chiprate	2.047 Mchips/s	1.023 Mchips/s	1.023 Mchips/s	--
Secondary code length	20 bit NH Code	N/A	N/A	

2.3 Navigation Message

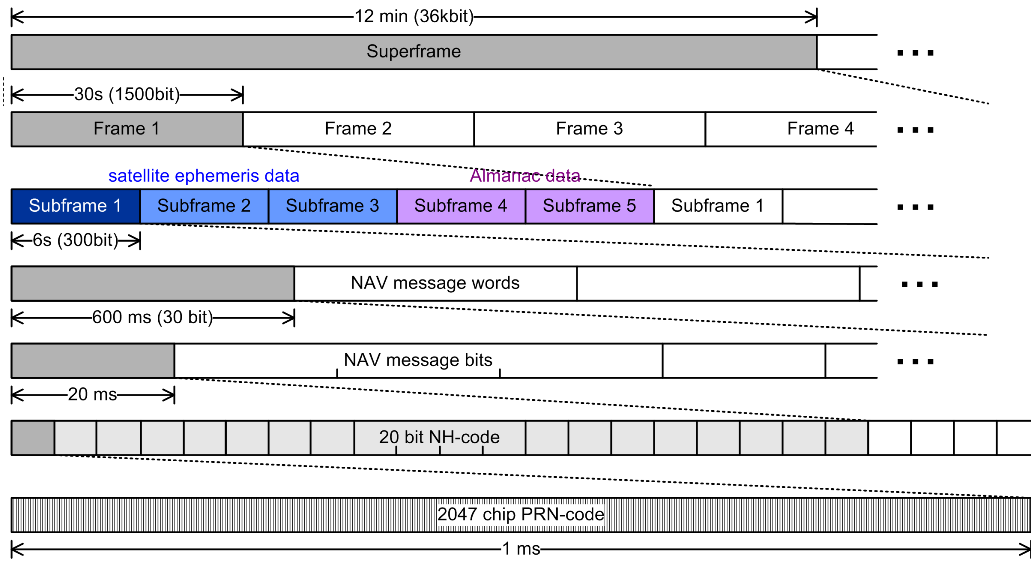


Fig. 2-4: BEIDOU signal structure: From chips (bottom) to Superframes (top).

Caused by the code division multiple access (CDMA) technique, a bit is formed by 2047 chips. Unlike GPS, BEIDOU uses a 20 bit Neumann-Hoffman (NH) secondary code: The NH code (0, 0, 0, 0, 0, 1, 0, 0, 1, 1, 0, 1, 0, 1, 0, 0, 1, 1, 1, 0) is modulated on the ranging signal with a bit duration of 1 millisecond.The NH code is transmitted either inverted or non inverteted and thus contains the bits of the navigation message.

The exact bit allocation of each subframe is shown in the BEIDOU Interface Control Document (ICD) [5]. 30 bits form a word and 10 words a subframe, making a subframe contain 300 bits and lasting 6 seconds.

Just like GPS, five subframes form a frame. Therefore, a frame consists of 1500 bits and needs 30 seconds to be transmitted. Subframes one, two and three contain necessary pseudo range measurement information. The whole signal structure is illustrated in figure 2-4.

To make sure that all necessary data is available and to provide some time for the tracking loops to lock onto the signal, it is reasonable to record about 35-40 seconds of data.

The most important ephemerides parameters are listed in table 2-2. The six Keplerian parameters are highlighted using bold italic letters.

Table 2-2: Ephemerides Parameter definitions

Parameter	Definition
t_{oe}	Ephemeris reference time
sqrt(a)	Square root of semi-major axis
e	Eccentricity
ω	Argument of Perigee

Parameter	Definition
Δn	Mean motion difference from computed value
M_0	Mean anomaly at reference time
Ω_0	Longitude of ascending node of orbit plane at weekly epoch
$\dot{\Omega}$	Rate of right ascension
i_0	inclination angle at reference time
iDot	Rate of inclination angle
C_{uc}	Amplitude of the cosine harmonic correction term to the argument of latitude
C_{us}	Amplitude of the sine harmonic correction term to the argument of latitude
C_{rc}	Amplitude of the cosine harmonic correction term to the orbit radius
C_{rs}	Amplitude of the sine harmonic correction term to the orbit radius
C_{ic}	Amplitude of the cosine harmonic correction term to the angle of inclination
C_{is}	Amplitude of the sine harmonic correction term to the angle of inclination

3 Instrument and Application Setup

BeiDou signals can either be generated using a SMBV100A, or live captured using an additional TSMW-Z20 GPS antenna. The following sections give an overview of how to handle the basic settings of GNSS simulation using an SMBV.

In February 2014, recording live BEIDOU signals is only possible within the Asia-Pacific area (longitude 55°E to 180°E and latitude 55°S to 55°N). China is planning to provide full global coverage by the year 2020.

The necessary software options for GNSS simulation using Rohde & Schwarz instruments are shown in table 3-1.

Table 3-1: Software options necessary for GNSS simulation with Rohde & Schwarz instruments

	BEIDOU	GALILEO	GPS
SMBV	K107 (6 sat) + K91 (extends to 12 sat) + K96 (extends to 24 sat)	K66 (6 sat) + K91 (extends to 12 sat) + K96 (extends to 24 sat)	K44 (6 sat) + K91 (extends to 12 sat) + K96 (extends to 24 sat)
WinIQSim2™	---	K266 (1 sat)	K244 (1 sat)

For more information about specific options, concern reading the SMBV [6] or WinIQ-Sim2 [12] DataSheet.

If the signal is live captured (e.g. using the TSMW-Z20 option), chapter 3.1, "Manual Operation of the SMBV", on page 10 can be skipped and reading can be continued with the IQR and TSMW sections of chapter 3.2, "Remote Operation ", on page 12.

3.1 Manual Operation of the SMBV

The first step on the SMBV is to do a **Preset** such that no former settings interfere with the current ones. Click on the **config…** box located inside the Baseband frame. A drop-down menu with a choice of different modulation types appears.

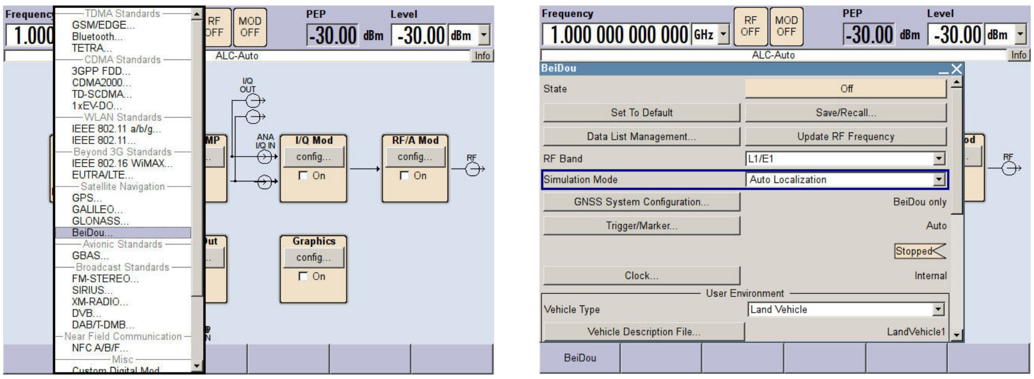


Fig. 3-1: Basic settings of the SMBV

Click on the **BEIDOU** element located in the Satellite Navigation subsection as shown on the left side of figure 3-1.

There are several simulation modes available in the SMBV as shown on the right of figure 3-1. **Auto localization** requires least user settings to perform positioning: The user is able to change the receiver localization by clicking **Localization Data**. There is either a list of several cities around the globe to choose from, or the coordinates can be completely user defined. The SMBV then calculates the orbits of all visible satellites and their navigation messages on its own.

Scrolling down to the bottom and clicking on **Satellite Configurations** opens a new window to manually tune the simulated satellite constellation (compare figure 3-2). Having selected **Auto Localization** before, all settings are already adjusted by the SMBV software. Increase **Ref. Power** to about **-60 dBm** to clearly visualize the CDMA modulated signal on a spectrum analyzer or the IQR screen later.

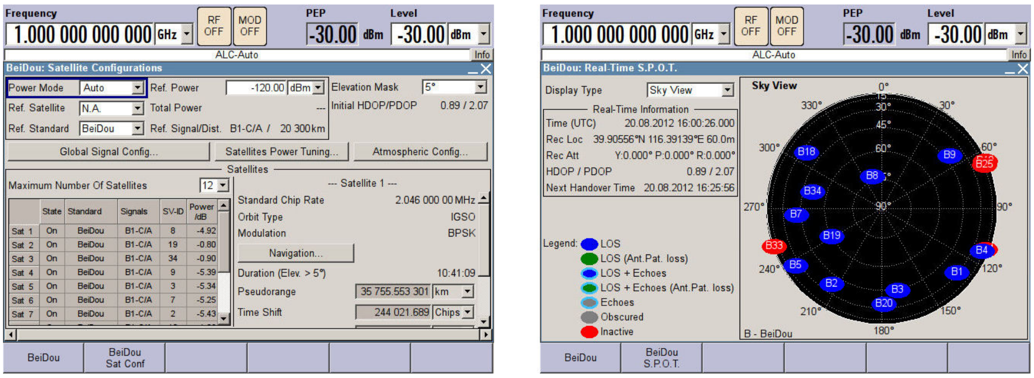


Fig. 3-2: Satellite Configurations (left) and Real-Time S.P.O.T. display (right).

Close the **Satellite Configuration** window to have a look a the realtime satellite and position online tracker display (**Real-Time S.P.O.T.**). All simulated satellites are visualized on a single screen. This screen can be used to compare whether all visible satellites have been acquired by the MATLAB application.

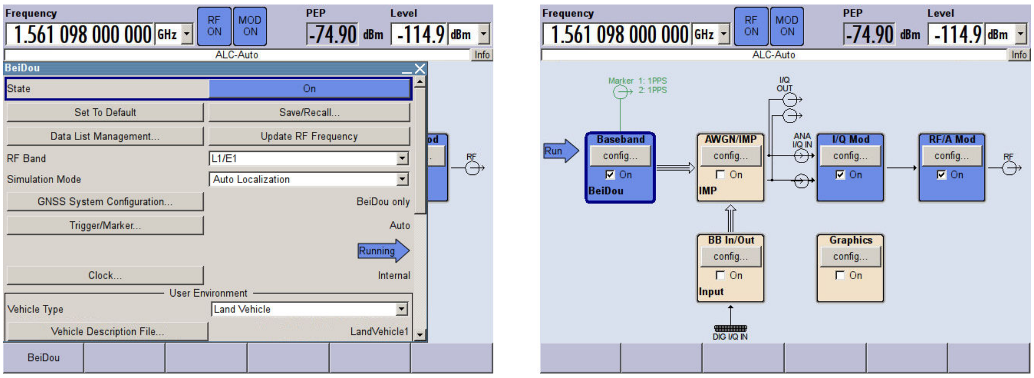


Fig. 3-3: Turning baseband modulation (left) and RF (right) ON

Close the **Real-Time S.P.O.T.** display and activate the baseband simulation by turning **State** to **On** (see figure 3-3). The SMBV is now calculating the baseband signal. To activate the RF output, either press the **RF OFF** key on the SMBV, or select **config …** in the **RF/A Mod** frame and turn **RF ON**.

The above actions do also apply on the generation of GALILEO and GPS signals. Please note again, that only the SMBV is able to generate BEIDOU signals.

3.2 Remote Operation

In order to remotely control the generator and the recorder, a LAN connection to the instruments has to be established. Furthermore, the MATLAB Instrument Control Toolbox (ICT) and all relevant drivers have to be installed (see chapter 3.2.1, "Driver Installation and Initialization", on page 12).

> The installation process is only briefly described in the below sections. For a more complete documentation on how to install VXIplug&play drivers consider reading application note 1MA171 [11].

3.2.1 Driver Installation and Initialization

- Download and install the required VXIplug&play drivers (spectrum analyzers [7], IQ Recorder [8], signal generator [9])
- Open MATLAB and create MATLAB instrument drivers using the makemid command: For example, the rsspecan driver can be created in the current working directory using the following command:
  `makemid('rsspecan', 'matlab_rsspecan_driver')`
  Please do not uninstall the instrument driver after this step. It is accessed by MATLAB when communicating with your connected instrument.
- The correct installation of the driver can be verified by clicking on the **Test & Measurement Tool** (TMtool) from the MATLAB Apps tab, or entering
  `>> tmtool`
  into MATLAB's command window.

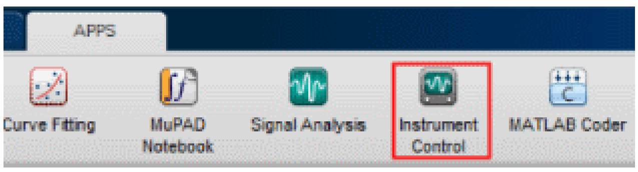


Fig. 3-4: TMtool placement on MATLAB APPS tab.

- In the TMtool left tree-structure window select ***Instrument Objects -> Device Objects*** and press the ***New Object ...*** button.
- Select the previously generated instrument driver and a valid VISA resource name (e.g.: *TCPIP::10.85.0.68::INSTR*). The object can now be created using the ***OK*** button (compare figure 3-5).

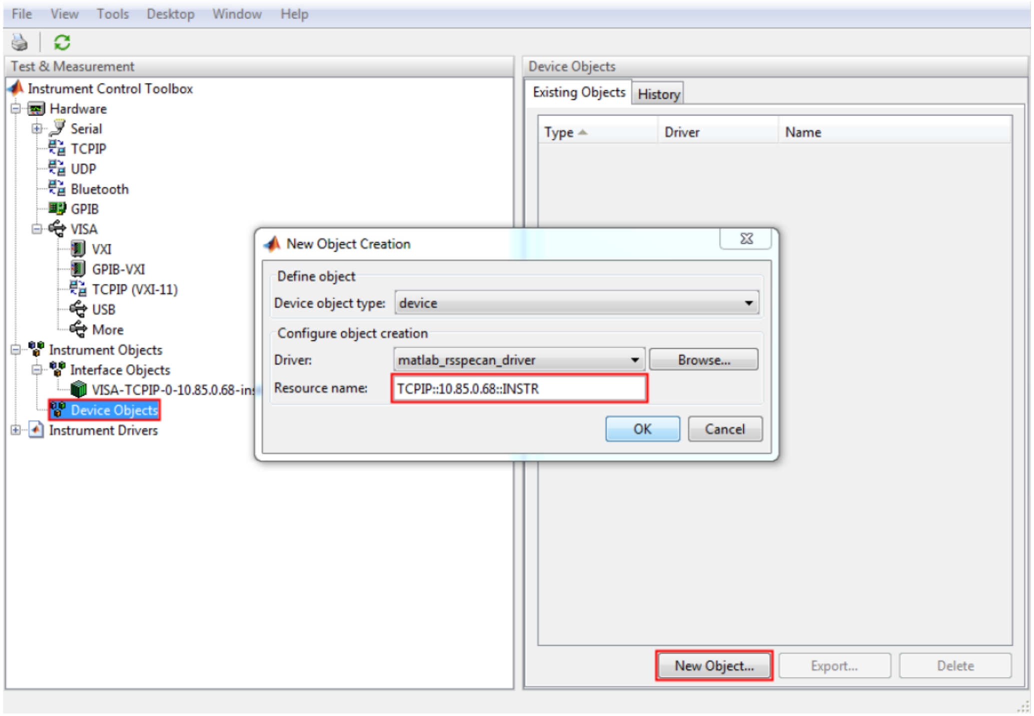


Fig. 3-5: Generation of a new instrument connection using the TMtool.

- A new device object is now visible in the tree structure. Click on it and establish a connection using the Connect /Disconnect buttons on the top right corner (see figure 3-5).
- The instrument's display should now confirm that the instrument is in remote mode.

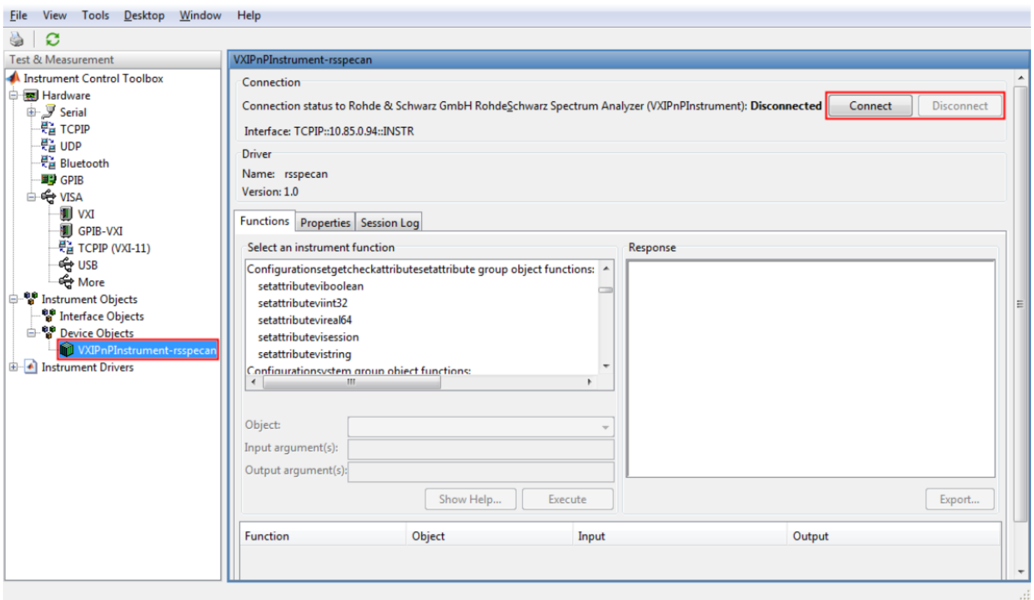
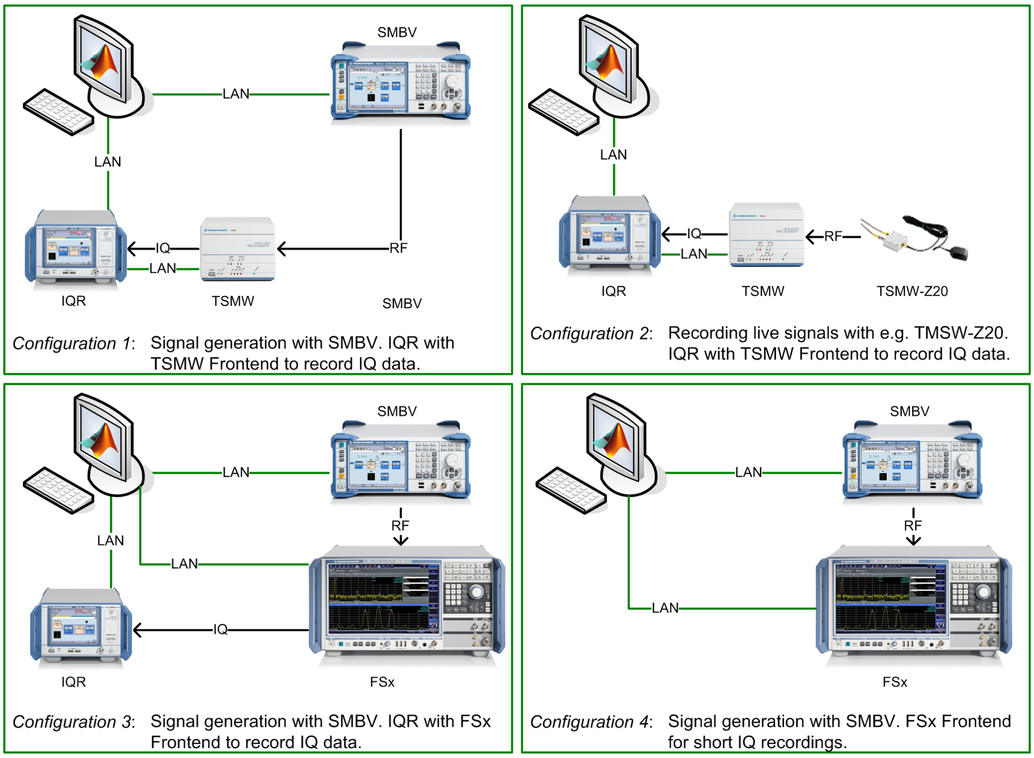


Fig. 3-6: Connecting to a recently added instrument using the TMtool.

You need to install and compile all necessary drivers for use in MATLAB.

3.2.2 Configuring the Instruments

For remote controlling, all necessary instruments need a LAN connection to the user computer. It is possible to use a wide range of Rohde & Schwarz spectrum and radio analyzers together with the application:



Configuration 1: Signal generation with SMBV. IQR with TSMW Frontend to record IQ data.

Configuration 2: Recording live signals with e.g. TMSW-Z20. IQR with TSMW Frontend to record IQ data.

Configuration 3: Signal generation with SMBV. IQR with FSx Frontend to record IQ data.

Configuration 4: Signal generation with SMBV. FSx Frontend for short IQ recordings.

Fig. 3-7: Different experiment setups remote controllable by the MATLAB application.

The GNSS signal can either be generated using a SMBV, or live captured using a GNSS antenna. Most GNSS antennas are active antennas to amplify the weak signals arriving from space.

NOTICE

DC current supply for active antennas

If an active antenna is used, make sure that no DC is supplied to the RF input of the TSMW, respectively FSx. The supplied DC voltage might exceed reverse power limits of the instrument and cause severe damage.

To avoid damage of the instruments, a DC blocker should be used. The TSMW-Z20 kit includes an active antenna, a power splitter, a DC blocker as well as all necessary cables and adapters

Long IQ recordings have considerable size. For records with a duration of more than a few seconds, an IQR is needed to store the arising amounts of data.

To avoid long waiting times while transferring the data, a Gigabit connection is recommended between the host PC and IQR. Transmitting the data directly to the user's PC requires a network drive mapped to IQR. After the configuration, the IQR should have access to a drive on the local computer linked with a unique drive letter (e.g. `C:\IQRStorage` on the remote computer should be accessible as `N:\` from the IQR).:

- On the PC running MATLAB, generate a new folder and enable sharing:
  - ***Right click -> Properties***
  - Browse to the ***Sharing tab*** and click on ***Sharing ...***
  - Add the users you want to share the folder with or select Everybody.
- Switch to the IQR and attach a USB keyboard. Press the ***Windows key*** and open a new explorer window.
- Browse to the shared folder on your local machine.
- ***Right-click*** on the folder and select ***Map Network Drive***
- Click on the drive letter you want to use and click ***Finish***.

Detailed information in other languages is available at the Microsoft support page [10].

Always make sure that the network drive is properly mapped on the IQR since file operations will fail otherwise. Easiest way is to open the network folder on the IQR and check that the containing data is the same as on the host PC.

If a TSMW is used in the setup (configurations 1 und 2), a workspace needs to be created within the IQR. Otherwise, the following section can be skipped and the next step will be to configure the application (see chapter 3.2.3, "Configuring the Application", on page 17):

TSMW Workspace creation

The TSMW is remote controlled by the IQR and is therefore connected with a separate LAN cable. Connect the *IQR LAN 1* with the user PC and the*IQR LAN 2* with the TSMW.

Switch on both the IQR and the TSMW and click on the ***TSMW Control*** button on the screen to start IQR-K1 option.

The workspace tab shows all saved workspaces. Create a new workspace for capturing Beidou signals:

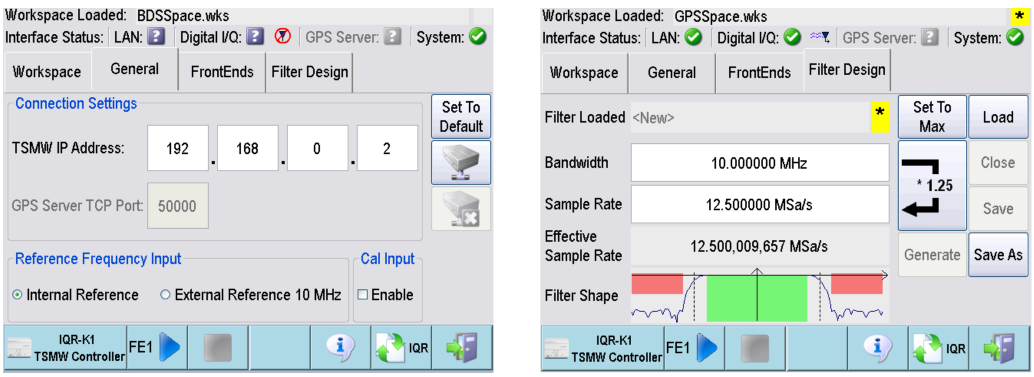


Fig. 3-8: Creating a new workspace for GNSS signal capturing (left). Baseband filter calculation (right).

- Browse to the General tab and check the IP address of the TSMW (default 192.168.0.2)
- Reference Input should be set to ***Internal***.
- Click on the hard drive image to connect the TSMW.

Now, a filter needs to be designed for BEIDOU, GPS and GALILEO signals (see right side of figure 3-8):

- Click on the ***Filter Design*** tab and set the disred bandwidth (5 MHz is usually a good tradeoff between processing time and accuracy).
- Push the ****1.25*** button and ***Generate*** to create a filter. The filter shape is visualized on the instrument screen (compare figure 3-8 on the right).
- Click on 'Save As' to give the filter a unique name and store it for future use. The name itself is of no matter to the MATLAB application since only the workspace will be called.

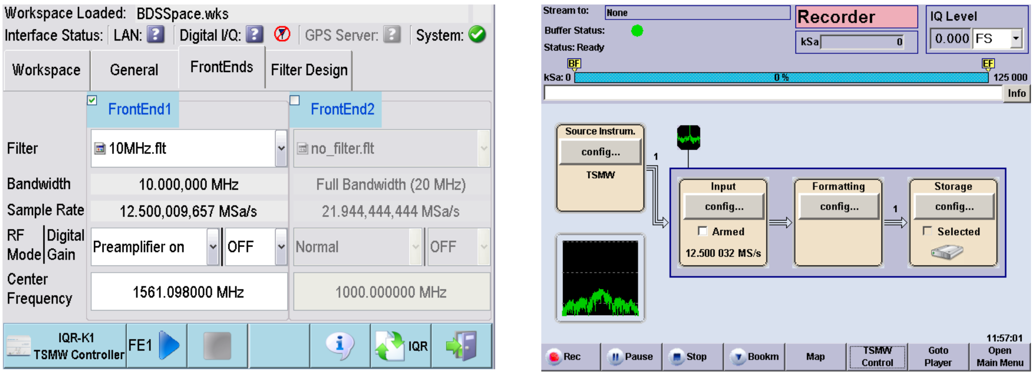


Fig. 3-9: Design a BEIDOU Front-end for the TSMW.

Tip on the ***FrontEnds*** tab to apply the recently created Filter.

- Select the recently created filter in the ***Filter*** drop-down menu and set the ***Preamplifier on*** and the ***Digital Gain OFF***. Beidou's center frequency is 1561.098 MHz
- Go back to the ***Workspace*** tab and click on ***Save as*** to store the workspace for later use. Name the workspace *BDSSpace.wks*.

Perform the same filter settings again to create both a GPS and GALILEO workspace. Adapt the center frequencies according to table 2-1 and name them *GPSSpace.wks* and *GALspace.wks*.

By clicking on the blue arrow, the current workspace is set active.

To test the created workspace, let the SMBV create a BEIDOU respectively GPS or GALILEO signal (see chapter 3.1, "Manual Operation of the SMBV", on page 10). Set the signal strength to -60 dBm to generate a well comparable spectrum.

You can switch to the IQR display again by clicking on the 'IQR' button. The spectrum plot in the main application should now display a CDMA typical spectrum with a characteristic main lobe and several side lobes.

3.2.3 Configuring the Application

The MATLAB application is simply installable by double-clicking on the *mlappinstall*-file contained in the .zip folder. After the installation process has completed an icon should be available under the MATLAB Apps tab. Click on it to start the application.

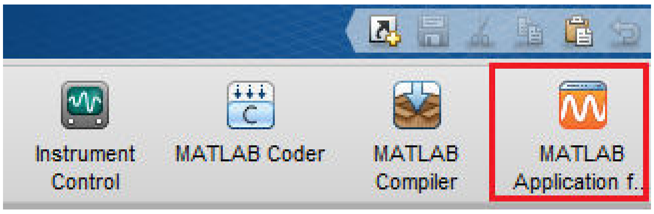


Fig. 3-10: MATLAB application for Beidou Tracking

It is possible to use a wide range of R&S spectrum and radio analyzers together with the MATLAB application as illustrated in figure 3-7. Depending on your configuration, different settings have to be applied:

Configuration 1

To use a TSMW together with an IQR for recording, select ***Settings -> Instrument -> Recorder -> LAN address*** and enter the IP-address or computer name of the IQR.

The network drive mapped on the IQR needs to be configured in the application too. Select ***Settings -> Storage -> Network Drive*** and enter the drive letter (e.g. `N`) mapped on the IQR.

Select ***Settings -> Instrument -> Generator*** and enter the IP address or computer name of the SMBV.

Since the TSMW is remote controlled by the IQR, no IP configurations for the TSMW are required.

Configuration 2

Together with the*R&S TSMW-Z20 GPS RF recording kit*, it is also possible to record live GPS, GALILEO and BEIDOU signals from space. Select ***Settings -> Instrument -> Recorder -> LAN address*** and enter the IP-address or computer name of the IQR.

The network drive mapped on the IQR needs to be configured in the application too. Select ***Settings -> Storage -> Network Drive*** and enter the drive letter (e.g. `N`) mapped on the IQR.

Configuration 3

To use an FSx Spectrum Analyzer as RF Front-end for the IQR, select ***Settings -> Instrument -> Recorder -> LAN address*** and enter the IP-address or computer name of the IQR. Select ***Settings -> Instruments -> Recorder -> Alternative Front-end*** and enter the IP-address or computer name of the FSx.

The network drive mapped on the IQR needs to be configured in the application too. Select ***Settings -> Storage -> Network Drive*** and enter the drive letter (e.g. `N`) mapped on the IQR.

Select ***Settings -> Instrument -> Generator*** and enter the IP address or computer name of the SMBV.

Configuration 4

In case you do not want to record long samples, it is also possible to use only a spectrum analyzer. Just enter the IP-address or computer name of the FSx at ***Settings -> Instruments -> Recorder -> LAN address*** and press ***OK***.

The application detects automatically that a spectrum analyzer is addressed and loads the corresponding driver. This is be realized by using SCPI commands and querying the instrument ID.

Finally, ***Settings > Storage > Storage Folder*** needs to hold information about the folder to which incoming data should be copied. (e.g.: `C:\IQRStorage`).

The application is now fully configured and ready to record GNSS data.

3.3 Remote Control examples

Pushing the ***Setup*** button located in the Generator Setup box calls a function named `SetupGeneratingInstruments()`. The function first checks whether a compatible instrument is connected and then uses the R&S MATLAB Toolit for Signal Generators (see application note 1GP60) for communication with the instrument.

The toolbox provides three main functions for communication:

- `rs_connect(varargin)`,
- `rs_send_query(instrObj, strCommand)` and
- `rs_send_command(instrObj, strCommand)`.

These functions can be used to connect and communicate with Rohde & Schwarz instruments and are based on SCPI commandos. The complete list of SCPI commandos with detailed information can be found in the SMBV Operating Manual [6]. Nevertheless, we will have a short look at the general procedure.

It is also possible to remote control the SMBV using attribute based drivers. The utilization of those drivers is exemplarily explained for FSW in application note 1MA171 [11] and can be adapted in order to control the SMBV as well.

When using a LAN interface, `rs_connect()` is called to setup communication with the instrument.

```
[status deviceObj] = rs_connect('tcpip', deviceIdent);
```

A full GNSS constellation can be achieved using only a few lines of code:

```
% Define the GNSS to be used: GPS | GAL | BEID
GNSS = 'BEID';

% Preset GNSS configuration:
rs_send_command(deviceObj, ['SOUR:BB:' GNSS ':PRES']);
```

```
complete = rs_send_query(deviceObj, '*OPC?');

% enter 'auto localization' mode:
rs_send_command(deviceObj, ['SOUR:BB:' GNSS ':SMOD AUTO']);
% set reference power to -60 dBm:
rs_send_command(deviceObj, ['SOUR:BB:' GNSS ':POW:REF -60']);
% set SMBV to simulate 'numSat' satellites:
rs_send_command(deviceObj, ['SOUR:BB:' GNSS ':SAT:COUN' numSat]);
% set Munich as location:
rs_send_command(deviceObj, ['SOUR:BB:' GNSS ':LOC:SEL "Munich"']);
% set GNSS state to 'ON':
rs_send_command(deviceObj, ['SOUR:BB:' GNSS ':STAT ON']);
% set I/Q mod 'ON':
rs_send_command(deviceObj, 'SOUR:IQ:STAT ON');
% set RF 'ON':
rs_send_command(deviceObj, ':OUTP ON');
```

The Generator ***Setup*** button is disabled while the instrument is applying changes. Therefore *Operation complete?* (‘`*OPC?`’) should be called after commands requiring recalculation of the signal. For better readability, those calls have been left out in the upper example.

The above example is taken from the `SetupGenInstruments.m` file available with this application note.

4 Working with the Application

The application needs to be fully configured before being able to remotely record IQ data. The complete configuration of the application (see chapter 3.2, "Remote Operation ", on page 12) is assumed in the following sections.

The application is able to remote control a signal generator in order to simulate GNSS signals which can be used for positioning by one simple click. Either a live signal, captured with a GPS antenna, or the simulated signal can then be recorded and analyzed by the application in order to process the ephemeris data received from the satellites.

Fig. 4-1: Main screen of the MATLAB application.

4.1 Basic Operation

Start the application by clicking on the corresponding icon in the Apps tab (see figure 3-10).

Selecting a Satellite System

The GNSS to be processed is selected using the radio buttons near the top of the application's main screen. It affects the signal generation as well as the signal recording by using different center frequencies and bandwidth (as configured within the IQR workspace. see chapter 3.2.2, "Configuring the Instruments", on page 14).

Generating a GNSS Signal

Generating a GNSS is not necessary if the signals are live captured using a GNSS compatible antenna (e.g. TSMW-Z20).

Referring to figure 4-1, the generator settings are situated in the area marked with a green rectangle. The number of satellites simulated by the SMBV can be varied between four and 24 using the drop-down menu. Generating more satellites slows down the tracking process significantly. Furthermore, the simulated position can be chosen from a Dropdown menu. Settings are applied by clicking ***Setup***.

The number of satellites is limited by the options installed on the SMBV.

- SMBV-K44 (GPS), K66 (GALILEO), K94 (GLONASS), K107(BEIDOU): able to simulate up to **6 satellites**.
- SMBV-K91: GNSS extension to **12 satellites**.
- SMBV-K96: GNSS extension to **24 satellites** .

Recording a GNSS Signal

The length of the GNSS recording can be changed using the box marked with the blue rectangle. Maximum record time is limited by the disc capacity of the instrument. Using an IQR and a sampling rate of 10 Msamples/s, one second of recorded data corresponds to approximately 50 Mbyte.

The sampling rate is determined within the IQR workspace. A lower sampling rate leads to faster processing but less precise positioning. A tradeoof between processing speed and accuracy is to take a sampling rate 5 MHz (see "TSMW Workspace creation" on page 15).

A click on ***Record*** starts the recording.

After the file is recorded, it will automatically be copied to the network folder mapped on the IQR.

Make sure that the network drive is properly mapped on the IQR. If not, copying the file will fail and the record has to be manually exported or data has be recorded again.

Processing the file will automatically start after the entire file is copied.

Processing a GNSS Record

When a new file is recorded, it will automatically be processed. If you want to manually process an older record, click on ***Open*** to manually load a file into the application.

In case an IQR recording is loaded (file extension '.wvd'), the sampling rate and duration are filled out automatically using the corresponding '.wvh' file. If the filename contains BDS, GPS or GAL, the application automatically adapts to the corresponding GNSS settings. If a '.dat' file is loaded, sampling rate and GNSS system have to be defined manually since no appropriate information is available in the file header.

If a '.wvd' file is copied, or moved, make sure to copy or move both the '.wvd' and '.wvh' file since otherwise important information will be lost.

If data is recorded using an FSx, sampling rate can be adjusted in the MATLAB file `setSamplingRate.m` in the `\\include` folder.

Click the ***Process*** button to start acquisition and tracking. The acquisition process will search for visible satellites and output a plot comparable to the Acquisition and Tracking Results in figure 4-2.

Fig. 4-2: Successful acquisition of eight BEIDOU satellites.

The acquisition is performed using a so-called *Parallel Code Phase Search Acquisition*: A cross correlation between a local replica of each satellite's PRN code and the incoming signal is performed in the frequency domain.

A two dimensional search space (see left side of figure 4-3) is spanned by the occurring Doppler frequency shifts and the PRN code shifts:

- The frequency resolution is determined by the length of the acquisition sample. Using a one millisecond sample with a sampling rate of 10 MHz, a frequency resolution of 1 kHz can be reached. For a low speed receiver, Doppler shifts of ±5 kHz have to be considered.
- The resolution of the PRN shift axis is directly dependent on the sampling frequency.

The main advantage transforming the signal using a discrete Fourier Transform is that the circular correlation necessary in the time domain corresponds to a simple multiplication in the frequency domain.

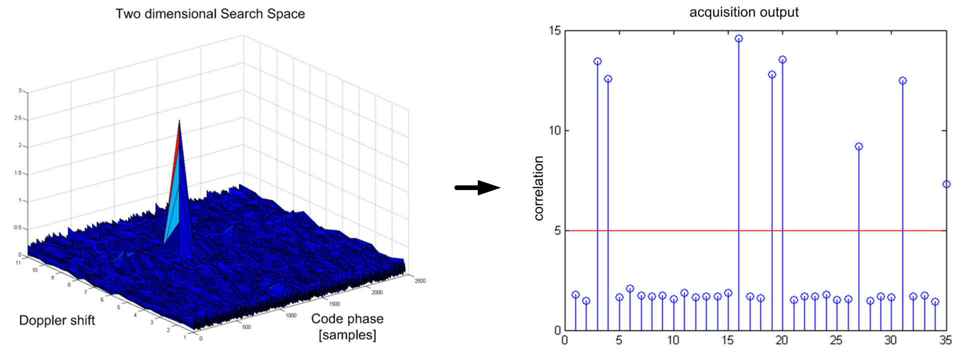


Fig. 4-3: Two dimensional Search space acquiring a single satellite (left) and Acquisition and Tracking Results output (right).

The algorithm compares the relation of the peak value with an average of the noise floor and marks the satellite 'visible' if a certain threshold is exceeded. The relation is plotted into the Acquisition and Tracking Results diagram (see right side of figure 4-3). The procedure is described in detail in [2] chapter 6.4 "Parallel Code Phase Search Acquisition".

As soon as acquisition is performed, the algorithm tries to track every acquired satellite. With the beginning of the tracking, a MATLAB output graph (called figure 1 in MATLAB) appears. It is illustratedon the left side of figure 4-4:

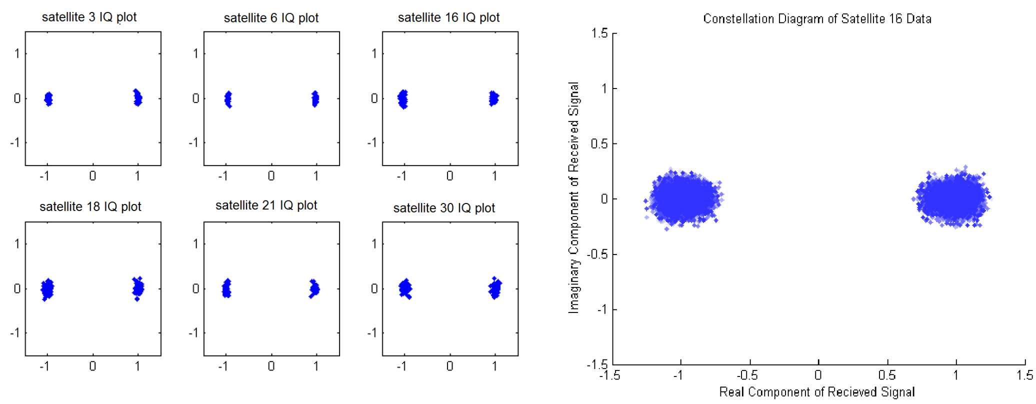


Fig. 4-4: MATLAB output graphs: IQ diagrams during tracking process (left) and after processing is completed (right).

It visualizes the IQ data of each visible satellite. The three main steps of the tracking process can be seen there: At the beginning, the IQ-plot looks more or less random. At the time, the code tracking is locked, the constellation looks like a perfect circle. A clear BPSK modulation scheme will be visible as soon as the phase tracking loop has found the optimum phase.

Phase accuracy and *frequency step during tracking* might need to be adapted to the signal strength for a successful tracking of the incoming signal:

Within typical application, *phase accuracy* should be set to a value in the range of 0.1 to 0.001 rad and *frequency step size* between 10 ... 0.001 Hz.

Detailed information on these settings is given in chapter 4.2, "Advanced Settings", on page 24.

After succesful tracking, to buttons become visible: The ***IQ Data*** button located inside the *Acquisition and Tracking Results* box generates a plot of the IQ data received by a single satellite. The satellite can be chosen using the drop-down menu. Exemplary IQ data is shown on the right side of figure 4-4. The more faint a data point is, the earlier it was recorded from the satellite.

The ***ephData*** button shows the ephemeris data transmitted by a single satellite. The satellite can be chosen using the drop-down menu. The ephemeris data is used for pseudo range measurement and positioning. The data is visualized in a table similar to figure 4-5. Ephemeris data used in BEIDOU, GALILEO and GPS is quite similar. More information on the data can be found in each system's interface control document (ICD).

Parameter	Value	Units	Definition
M_0	0.1696	semi-circles	Mean Anomaly at Reference Time
delta n	5.1649e-09	semi-circles/sec	Mean Motion Difference Drom Computed Value
e	0.0130		Eccentricitc
sqrt(a)	3.0382e+03	sqrt(meters)	Square Root of the Semi-Major Axis
Omega_0	2.4981	semi-circles	Longitude of Ascending Node of Orbit Plane at Weekly Epoch
i_0	-0.9506	semi-circles	Inclination Angle at Reference Time
omega	2.5926	semi-circles	Argument of Perigee
Omega^dot	-7.4066e-07	semi-circles/sec	Rate of Right Ascension
I^dot	5.5824e-10	semi-circles/sec	Rate of Inclincation Angle
C_uc	6.2585e-07	radians	Amplitude of the Cosine Harmonic Correction Term to the Argument of Latitude
C_us	5.1804e-05	radians	Amplitude of the Sine Harmonic Correction Term to the Argument of Latitude
C_rc	193.0625	meters	Amplitude of the Cosine Harmonic Correction Term to the Orbit Radius
C_rs	1.0134e+03	meters	Amplitude of the Sine Harmonic Correction Term to the Orbit Radius
C_ic	6.0847e-05	radians	Amplitude of the Cosine Harmonic Correction Term to the Angle of Inclination
C_is	2.9802e-07	radians	Amplitude of the Sine Harmonic Correction Term to the Angle of Inclination
t_oe	462240	seconds	Reference Time Ephemeris (see GPS-ICD paragraph 20.3.4.5)

Fig. 4-5: Ep-hemeris parameters transmitted by the satellite (right).

4.2 Advanced Settings

There are different user definable settings which influence the behavior of the tracking algorithm. The advanced settings are reachable by clicking **Settings -> Advanced** inside the application's menu.

Default values for each setting are given in brackets. These values will match to the SMBV default settings applied by clicking on 'Setup' within the application's main screen.

- ***milliseconds used for acquisition*** defines the length of the sample used to acquire visible satellites. Small values increase the speed of the acquisition process, but weak satellites might be ignored. Higher values slow down the acquisition process but enables the algorithm to find even weak satellites and increases the accuracy of the Doppler estimation. Selecting more than 10 milliseconds leads to immense calculation periods but does not improve the accuracy of the receiver. [Default: 3]
- ***Detection level during acquisition*** needs to be adapted when increasing the length of the acquisition signal. It should usually be set to any value between 2 and 10. The detection value is plotted as a red line into the Acquisition and Tracking results and can be edited by inspection. [Default: 5]
- ***Phase accuracy in tracking loop*** defines how precisely the phase should be tracked within the phase tracking loop. Higher values lead to bigger signal constellation points, while smaller values may lead the system to loose track in case of phase shifts caused by multipath propagation. [Default: 1e-2]
- ***Frequency step size in tracking loop*** determines the maximum frequency steps, the local oscillator can be adapted after processing a single frame of the GNSS signal. The step size needs to be large enough to find track at the beginning of the signal. If the step size gets to big, the frequency locked loop will get out of track causing a loss of the satellite. [Default: 2e-1]

5 References

All references mentioned in the application note in order of their appearance:

[1] P. Misra and P. Enge: GPS - Signals, Measurement and Performance

[2] K. Borre, D. M. Akos, N. Bertelsen, P. Rinder, S. H. Jensen: A Software-defined GPS and GALILEO Receiver

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[4] ESA Navipedia. Available http://www.navipedia.net/index.php/Binary_Offset_Carrier_(BOC)

[5] China Satellite Office: BeiDou Navigation Satellite System - Signal In Space Interface Control Document for Open Service Signal B1I (version 1.0) http://www.beidou.gov.cn/attach/2012/12/27/201212275f2be9ad57af4cd09c634b08d7bc599e.pdf

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[7] Rohde & Schwarz, VXIplug&play driver for spectrum analyzers. Available: http://www.rohde-schwarz.com/en/driver/fsw/

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6 About Rohde&Schwarz

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