BTM41x Low Power

Application Note v1.1

1 Introduction

Low power consumption presents a major challenge for wireless devices. Increasing numbers of battery driven devices, as well as environmental aspects, are main drivers of demand for optimised power consumption. Power should not be wasted, consumed only when it is most needed.

This document describes strategies for low power consumption in Bluetooth technology, including sniff mode and sniff sub-rating. It explains the sniff mode configuration for BTM41x and gives examples. This illustrates the trade-offs between certain parameters in optimising power usage for particular use cases.

Topics related to power consumption (such as discoverable/connectable mode) are also covered.

For readers who want to get results quickly, read the following sections first:

- "5 Guidelines"
- "6.4.8 The Optimal Setting for a Real World Example"

2 Principle of Low Power Consumption

To realize the goal of consuming power only when it is most needed, we must identify the following:

- **Power:** Which entities of BTM41x consume significant amounts of power?
- **Most needed:** In which situation do we need these entities and when can they possibly be disabled?

The response to these queries for a BTM41x in SPP (serial port profile) connected state are:

- The 2.4 GHz radio of the BTM41x consumes significant power for data reception and transmission.
- The radio is most needed whenever data must be transmitted over the SPP link. When no data is about to be sent or received, the radio can be disabled in order to save power.

This is the principle of the sniff mode: the power-hungry radio is disabled when no data is to be transmitted or received (sleep phase). The radio is re-enabled periodically (wake-up) on both ends for two reasons:

- To keep the link alive (synchronisation)
- To send/receive any data accumulated in the UART buffer during the sleep phase

The duration of one wake phase and one sleep phase is called *sniff interval*. The sniff interval can be configured by S-Registers on the BTM41x.

The fact that serial data accumulates in the UART buffer during a sleep phase reveals a typical characteristic of sniff mode: a trade-off between power-saving versus data latency. The longer the sniff interval, the more power is saved while data latency increases.

Configuration of the sniff interval allows optimisation corresponding to expected data volume, data frequency, etc. Further measures exist in sniff mode to ensure improved data throughput and minimal latency in the case of 'unexpected' additional data. See Sniff Mode Parameters for additional information.

When not in a connection, significant power is consumed by page scanning (being connectable) and inquiry scanning (being discoverable). S-Registers to adjust these parameters are described in Discoverable/Connectable Status.

Finally, the UART baud rate is another parameter that affects power consumption. A higher baud rate means higher power consumption.

3 MEASURING POWER CONSUMPTION

Electrical power is defined as the product of voltage and current (P = V * I). Assuming a constant supply voltage for the BTM41x, the power is linear proportional to the current. In other words, by measuring the current we always obtain a value which is proportional to the power.

For this application note, the current was measured by using a current clamp (Fluke i30s) and oscilloscope (PicoScope) for device A (blue).

Alternatively, a shunt resistor in the range between one and three Ohms can be used. The shunt resistor is inserted in the BTM41x's power supply path. The voltage drop across the shunt resistor is proportional to the current (I = V/R). However, this method consumes two analogue inputs of the oscilloscope and requires the capability of displaying the difference between two channels (A-B).

If the BTM41x's power supply and UART connection is fully decoupled from the measuring system (no common grounds at all), then the shunt resistor method is also possible with only one scope channel. Decoupling of the supply can be achieved by powering the device from a battery pack. Decoupling the UART can be achieved by configuring that device for remote AT parsing (ats536=1; ats531=2; ats0=1). When connecting to the decoupled device, the CONNECT… message followed by an OK indicates remote command mode. Use ATI4 to verify. ATI60=2 also indicates remote command mode. This option was chosen for device B (red) measurements in this application note.

When looking at the oscilloscope screen, the area below the current curve represents the energy consumed. The goal of minimising power consumption corresponds to minimising this area. Ideally, only a few peaks presenting the sniff- /SSR interval, should be measured whenever no data is being exchanged.

4 CONFIGURATION OF BTM41X FOR LOW POWER CONSUMPTION

The majority of this section contains theory and configuration details related to power consumption of the BTM41x. Section 6.4 presents practical examples, screenshots, and guidelines for optimised power settings.

4.1 Discoverable/Connectable Status

When not in a connection, BTM41x is in one of four states:

- Neither discoverable nor connectable
- Discoverable
- Connectable
- Discoverable and connectable

When the module is discoverable, it performs *inquiry scanning*. This means it spends energy to detect other devices' inquiry requests and to respond to incoming requests.

When the module is connectable, it performs *page scanning*. This means it spends energy to detect (and respond to) other devices' connection requests.

Page and inquiry scanning are periodic activities with parameters for the duration of the scan window (the actual scanning phase) and the scan interval (scanning plus sleeping phase).

Less scanning time means less power usage. However, it also means a decreased probability of being found or connected by other devices. This results in a longer inquiry and/or connection process.

There are four S-registers controlling scan windows and intervals:

- S508 – Page scan interval in milliseconds
- S509 – Page scan window in milliseconds
- S510 – Inquiry scan interval in milliseconds

- S511 – Inquiry scan window in milliseconds

There is a command group AT+BT<m> allowing immediate change of the scanning state as follows:

- AT+BTQ – Make discoverable only
- AT+BTG – Make connectable only
- AT+BTP – Make discoverable and connectable
- AT+BTX – Make not discoverable and not connectable

S-register 512 selects which mode is entered at boot time (extra AT&W needed):

- 1 = not connectable, not discoverable
- 2 = discoverable
- 3 = connectable
- 4 = discoverable and connectable

ATI27 queryies the current mode at any time:

- 0 = not discoverable, not connectable
- 1 = discoverable
- 2 = connectable
- 3 = discoverable and connectable

Even while connected, the BTM41x must still be in one of the four scanning states. Due to the fact that the BTM41x only supports SPP and only a single point connection, there is no need to be discoverable or connectable. Hence, the only reasonable scanning state in a connection is *not connectable, not discoverable*.

Section 6.4.2 contains figures that help explain these settings as well as guidelines for optimised settings.

4.2 Active Mode

With a connection (SPP) in active mode (sniff mode disabled, S561=0), both ends are forced to keep all circuitry fully active, regardless of whether data is being exchanged. This permits best data throughput and lowest latency. At the same time, active mode causes continued high power consumption. When no data is being transmitted, energy is wasted. Active mode is the default setting of the BTM41x, but should be avoided for low power operation. Instead, sniff mode with a suitable Timeout value (T) is strongly recommended.

When connected (SPP), use ATI44 to determine if the device is in active mode. If it returns zero for the first parameter, the module is in active mode.

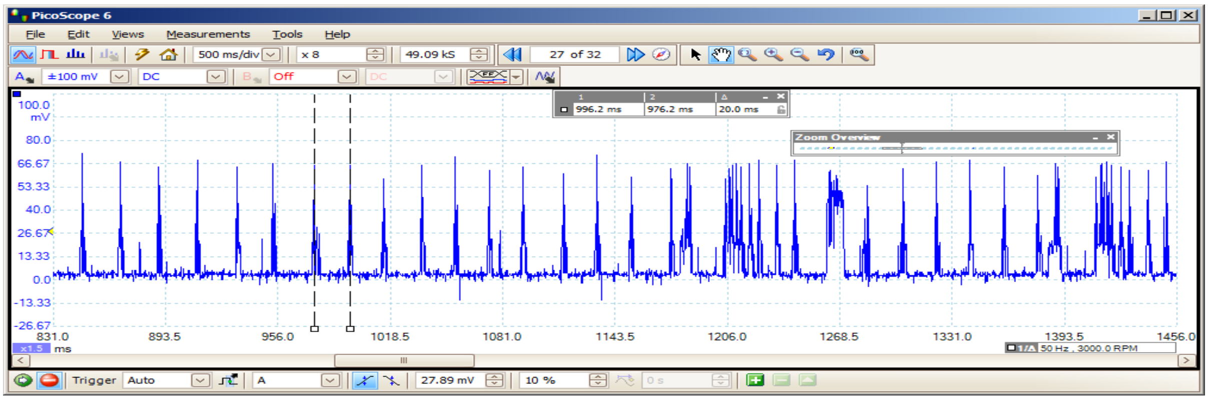

Figure 1: SPP, active mode, Master, no serial data exchange, 22.5 ms "polling"

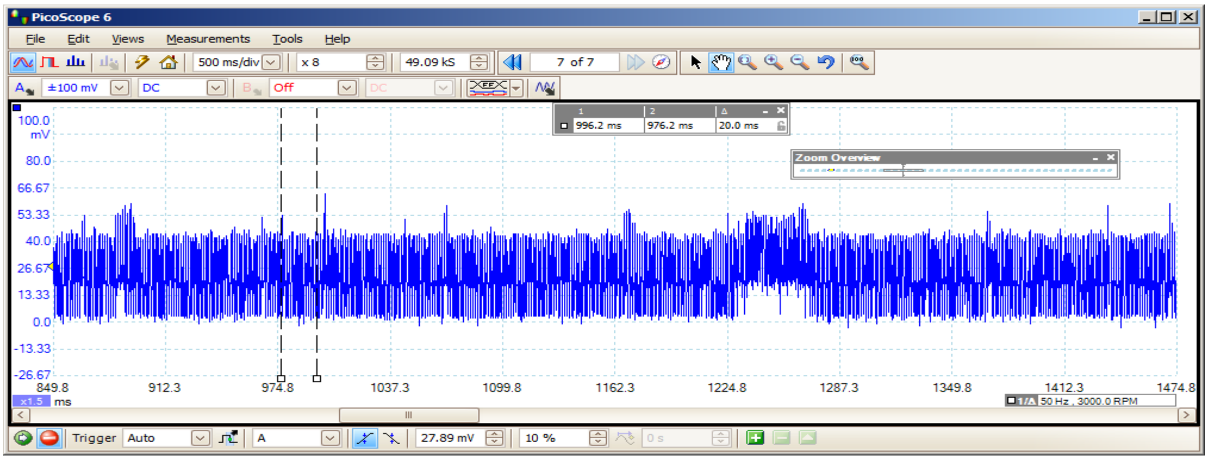

Figure 2: SPP, active mode, Slave, no serial data exchange

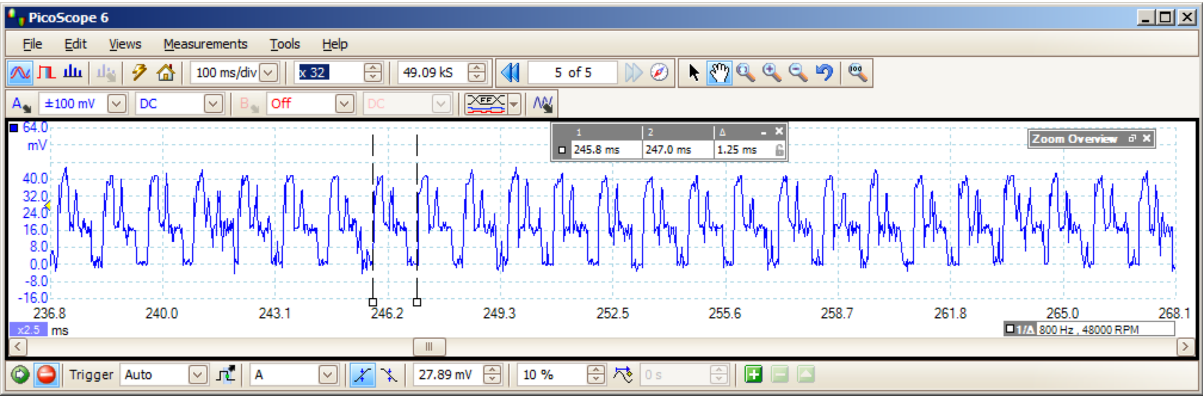

Figure 3: SPP, active mode, Slave, no serial data exchange, pair of TX/RX slots = 1.25 ms

4.3 Passive Mode

Passive mode is not a defined power mode in the Bluetooth specification. Passive mode describes a status of the BTM41x in which it does not initiate any power mode changes. No requests for sniff mode or for active mode are sent. Incoming requests for power modes are accepted.

Passive mode is indicated by '2' as the first response parameter to ATI44.

4.4 Sniff Mode

In a connection (SPP) with sniff mode enabled (S564 > 0), both ends agree not to exchange any data after an activity phase within an agreed sniff interval. The power-hungry radio is disabled after the activity phase for the remainder of the sniff interval (sleep phase). The sniff interval is determined by S564[1] (max. sniff interval, milliseconds). The activity phase is determined by S561 (Attempt, N). An additional parameter (T) extends the activity phase. Any data transmitted during the activity phase resets this timer.

Even if locally disabled (S561=0), the peer device may request and initiate sniff mode. The peer device provides the sniff parameters (attempt, timeout, and interval) which are accepted by the local BTM41x.

Sniff mode is indicated by '1' as the first parameter in response to ATI44, followed by the current sniff interval in slots.

4.4.1 Sniff Mode Parameters

Sniff mode is composed of three parameters:

- Attempt (N) – The amount of time (or number of slots) spent in active mode to keep the link alive and synchronised and to send/receive any data available. (N) is configured by S561 in milliseconds (attention: see section 6.2). See sniff register mapping for possible values (section 6.3.1, Table 6-3).

- **Sniff interval (M)** – The amount of time (or slots) from the beginning of the most recent activity phase until beginning of the next activity phase. The duration of the sleep phase is determined by M-N if no data exchange occurs. Sniff interval is configured in milliseconds by S564[1]. See sniff register mapping for possible values (section 6.3.1, Table 6-3).
- **Timeout (T)** – The extension of the activity phase if any data exchange occurs. The timer is reset with each data exchange during the activity phase. If no more data exchange occurs and the timer expires, then sleep phase is entered. This allows the activity phase to adjust itself dynamically to varying amounts of data. As a result, 'unexpected' amounts of data will be exchanged with lower latency and higher throughput. It is also possible that, due to continued data traffic, the timer T is still running when the next sniff interval commences, overlapping with the next attempt window. This will effectively skip the sleep phase and look like active mode (see Figure 5). Timeout is configured in milliseconds by S562. See Sniff register mapping for possible values (section 6.3.1, Table 6-3).

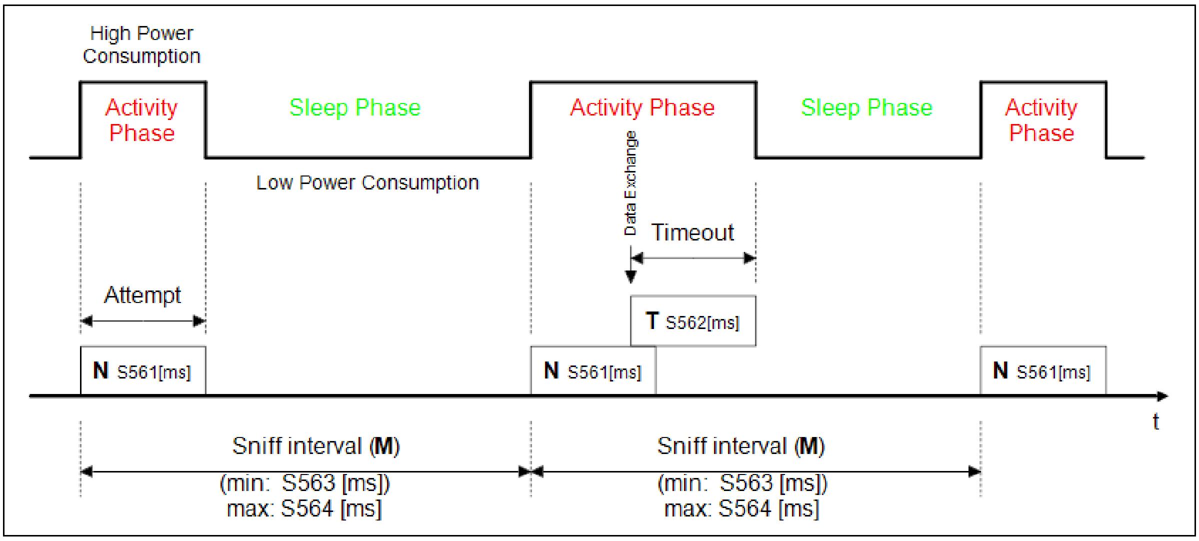

Figure 4: Sniff mode parameters

On the BTM41x, sniff mode is active when S561 (sniff attempt) contains a value greater than zero. The user must ensure that all other sniff registers (S562…S564) contain reasonable values at this point.

[1] Note: for S 563 please refer to observation no. • in section 4.4.2

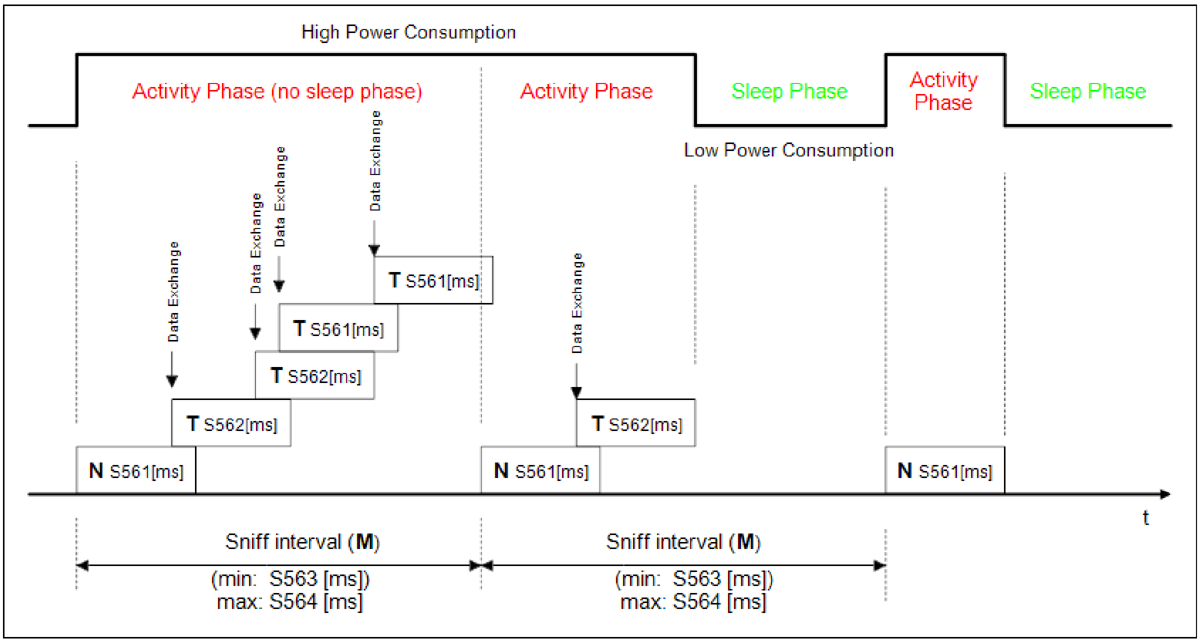

Figure 5: Sniff mode with increased data exchange

4.4.2 Slots vs. Milliseconds

Sniff parameters are passed to the baseband in units of Bluetooth slots. The duration of a slot is fixed at 0.625 milliseconds. Where S-Registers are set in units of milliseconds, AT firmware converts the milliseconds-value into slots by multiplying by 1.6.

The "Sniff mode and Sniff-Subrating Whitepaper" of the BT SIG [1] distinguishes between master (TX) and slave (RX) slots. Hence, one slot can also be referred to as the RX/TX pair of slots with a total duration of 1.26 ms.

The actual implementation in BTM41x refers to a slot length of 0.625 ms. An issue with this was observed; Refer to section 6.2 for additional information.

4.4.3 Sniff Mode S-Register Mapping

All Sniff mode configuration S-registers [S561…S564] have been assigned a mapping according to Table 6-3. Refer to section 6.3.1 for additional information.

4.4.4 Sniff Mode Observations

This section describes a number of characteristics that were observed in a link between two BTM41x's.

- A sniff mode request from either end is generally accepted by the opposite end. The resulting sniff mode parameters (sniff interval, for example) are identical to the parameters of the initiating device. Sniff mode parameters set in the accepting device do not take effect. Sniff mode is entered with parameters set by the initiating device.
- For basic sniff mode configuration, the sniff mode request is issued immediately after the link has been established. If sniff mode parameters are configured on both ends (basic configuration), both ends request sniff mode with its configured parameters. Given that all sniff mode requests are accepted, the device whose request occurs later dominates the sniff parameters.
  This process is driven by randomness. It cannot be assumed that the parameters of the master are dominant. Delayed sniff mode (see section 4.4.6**Error! Reference source not found.**) provides a mean to limit randomness, but this is an experimental feature.
- A sniff mode request can be issued at any time from either end, whether the link is in active mode or sniff mode. Delayed sniff mode (see section 4.4.6) allows a certain level of control for this.
- The role of a device (master/slave) does not impact the resulting sniff mode parameters.

- In sniff mode between two BTM41x, the value of S564 (maximum sniff interval) always takes precedence over S563 (minimum sniff interval). Nevertheless, AT firmware forces S563 to be less than S564. Although S563 does not seem to have any impact on the use cases covered by this document, it should be set as well. For most of the samples here, S563 was set to 100 or 10 milliseconds less than S564.
- This sniff interval range (min. S563 / max. S564) is intended for multipoint applications, but multipoint is not supported by BTM41x.
- Changing sniff mode parameters on the link always initiates active mode before re-entering sniff mode with new parameters. Power consumption is high for a short period of about 100 ms (observed, but may vary). See Figure 6.
- Sniff mode intervals are symmetric. They apply to both ends.

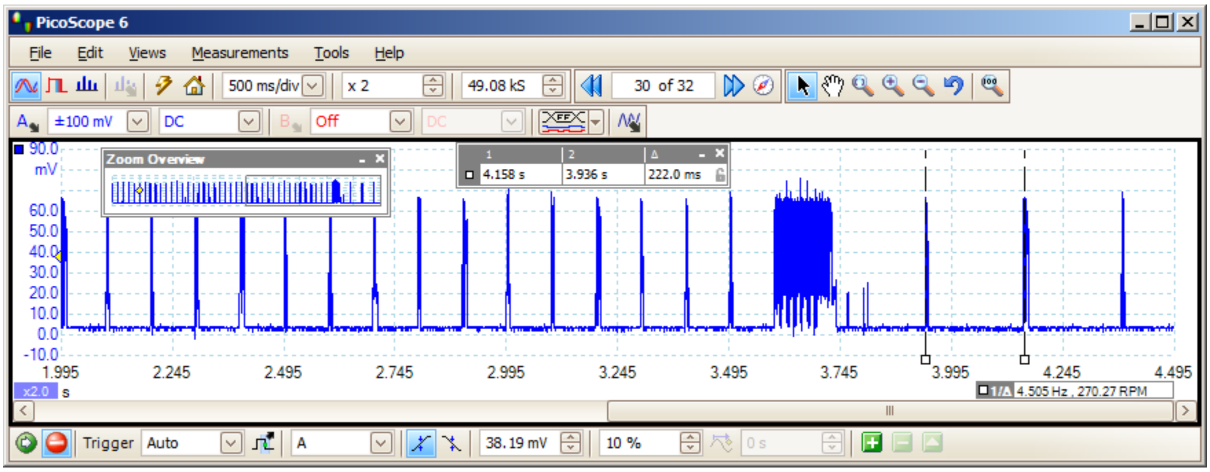

Figure 6: Change of sniff interval from 100 ms -> 220 ms, passing through active mode

4.4.5 Basic Configuration (S364=0)

Basic sniff mode configuration means that just S561 … S564 are utilised to configure sniff mode. Whenever a SPP connection is established, BTM41x will request sniff mode with its configured parameters and the request should be accepted by the other end. The remote device can also request new sniff parameters at any time and BTM41x will accept them. There is no notification of this. However, ATI44 / ATI144 allow verification of the current power mode (0=active / 1=sniff / 2=passive) as well as the current sniff interval in slots (ATI44) or milliseconds (ATI144).

Section 6.4.4 contains examples to visualize current patterns of sniff mode.

4.4.6 Delayed Sniff Mode (S364>0)

One disadvantage of basic sniff mode configuration is the undetermined result of which end's sniff mode parameters apply when BTM41x units on both ends have sniff mode parameters (S561…S564) set.

Delayed sniff mode may be useful if the remote end is requesting unsuitable sniff parameters and if there is no control on the remote end's parameters. If these conditions are false, delayed sniff mode is not recommended. It is experimental and has not been tested against devices other than the BTM41x.

4.4.6.1 Link Policy Power Table

Internally, sniff mode parameters are organised in a so called "link policy power table", containing a number of rows.

For basic sniff mode, the table contains effectively one row only, row[0] which contains sniff parameters of S561…S564.

For delayed sniff mode, the table contains row[0] for the delay and row[1] for the sniff parameters.

Each row contains the four sniff mode parameters (attempt (N), timeout (T), interval (M) max and min), as well as two more parameters: duration and power mode.

Duration determines the time after which the next row in the table is activated, if no data is being exchanged on the link. If any data is being exchanged, the first row is immediately activated.

Power mode can be active (0), sniff (1), or passive (2). The four sniff mode parameters are ignored if power mode is active or passive.

This feature allows gradually increased power savings over time if no data is being exchanged. However, latency for the first data increases as well over time. This concept addresses requirements of a Bluetooth keyboard and mouse.

On the BTM41x a simplified link policy power table with a maximum of two rows is implemented. It does not allow full configuration of the table, but serves two purposes:

- To apply sniff mode parameters to the link with a delay, set S364 (duration of first row).
- To choose the first row power mode either active or passive, set S365.

The first purpose increases the probability that the local sniff mode parameters will apply to the link persistently, given that the remote end requests its sniff parameters immediately or at least earlier than the local device. If the remote device should issue sniff requests at a later time, then the remote parameters will apply to the link.

The default power mode for the first row is passive (S365=0). It can be chosen to be active (S365=1), but this is not recommended due to the following reason: the first row is activated as soon as data starts being exchanged. If the power mode is 'active', then there will be at least one second of high power consumption even if only a few bytes of data are exchanged. Furthermore, if a few bytes are exchanged at regular intervals, then active power mode in first row (S365=1) proves itself as contrary to low power consumption.

Delayed sniff mode is enabled by setting a duration >0 to S364. If S364=0, then the internal link policy table will consist of one row only. The result is basic sniff mode configuration as described in section 4.4.5. Table 4-1, Table 4-2 and Table 4-3 give some examples of lpp_tables resulting from various settings for S364 and S364.

Table 4-1: Example link policy power table (S364=3, S365=0)

Row	Duration	Power mode	Sniff mode parameters (N,M,T)
[0]	3s [S364=3]	Passive [S365=0]	Ignored
[1]	Indefinite	Sniff	as per [S561 … S564]

Table 4-2: Example link policy power table (S364=2, S365=1)

Row	Duration	Power mode	Sniff mode parameters (N,M,T)
[0]	2s [S364=2]	Active [S365=1]	Ignored
[1]	Indefinite	Sniff	as per [S561 … S564]

Table 4-3: link policy power table, S364=0 = basic configuration

Row	Duration	Power mode	Sniff mode parameters (N,M,T)
[0]	Indefinite [S364=0]	Sniff [S365 is ignored]	as per [S561 … S564]

4.5 Sniff Sub-rating

In Bluetooth specification 2.1 +EDR, a new feature called Sniff Sub-Rating (SSR) was introduced. It allows devices which are already in sniff mode to extend their sniff intervals to an integer multiple of the current sniff interval after a defined time of no data being exchanged.

SSR is useful in scenarios where data exchange is followed by prolonged inactivity, e.g. a computer mouse or SPP applications with similar characteristics.

Sniff Sub-Rating is configured indirectly as policy. This means parameters are set as maximum or minimum values, but the final decision on actual parameters is made by the baseband.

4.5.1 SSR Parameters

Sniff sub-rating mode is composed of 3 parameters:

SSR (maximum) remote interval [S348] - The maximum amount of time (or number of slots) the remote device allowed to be absent in SSR mode, also referred to as maximum remote latency. SSR interval is set by S348 in milliseconds. The resulting SSR interval in a link can be less than the specified value, due to the fact that the SSR interval must be a whole-numbered multiple of the current sniff interval.

(Minimum) remote timeout [S349] - The minimum amount of time (or number of slots) the remote device must remain in sniff mode before entering SSR when no more data is being exchanged.

(Minimum) local timeout [S350] - The minimum amount of time (or number of slots) the local device must remain in sniff mode before entering SSR when no more data is being exchanged.

The basebands of both ends cross check the local S350 and the remote device's S349 in order to determine the resulting local timeout. The greater value applies. See SSR examples in section 6.4.7.

4.5.2 Sniff Sub-Rating S-Register Mapping

All Sniff Sub-rating S-registers [S348...S350] have been assigned a mapping according to Table 6-4. Please also refer to section 6.3.2.

4.5.3 Querying Actual SSR Parameters

ATI45 allows querying the actual values of all current SSR parameters (in slots): SSR mode active / not active, local SSR interval, remote SSR interval, local timeout, remote timeout. ATI145 serves the same purpose but response is in units of milliseconds.

Refer section to 6.3 for details on ATI45 / ATI145.

4.5.4 Observations

The following characteristics of SSR were observed between two BTM41x:

- Benefits the remote end: Setting SSR parameters locally (maximum remote interval) benefits the power savings of the remote device. Whether power savings are feasible on the local end depends on remote SSR settings.Only the BTM41x is covered as the remote device here. No comments can be made on other remote devices at the moment.
- Non-symmetric: SSR can be entered, even if only configured at one end. Thus, one end may be allowed a greater absence (multiple integers of current sniff interval) in sub-rating whereas the other end remains with the current sniff interval.
- Switching back and forth between SSR and sniff mode: As soon as any data is transmitted, the link autonomously reverts from sub-rating back to sniff mode. If no data is being transmitted in sniff mode, when the SSR timeout expires, the link autonomously re-enters sub-rating. This process does not pass through active mode by design. Compared to applying modified sniff mode parameters to a link, which always has to pass through active mode (meaning high power consumption), the autonomous SSR/sniff mode transition presents another advantage in terms of power saving. See example in section 6.4.7.1.
- Integer multiples: The resulting SSR intervals can only be whole-numbered multiples of the current sniff interval. Given that the sniff interval cannot be determined in every case in advance (remember: a request for sniff mode parameters is generally accepted), but the SSR interval is configured as absolute value (S349, maximum remote latency), the baseband calculates the value that suits all requirements. Due to this, the resulting SSR interval (ATI45/145) may not always correspond exactly to the value set in S349. See example in section 6.4.7.3.

Please refer to section 6.4.7 for a number of commented examples illustrating the above observations.

5 GUIDELINES

With the findings of this document, the following guidelines for improvement of power consumptions in can be given:

In general:

- Be aware that power savings trade off against data latency
- If possible, always enable sniff mode, at least with a small sniff interval (20..50 ms, e.g. ATS564=20)
- Set the timeout value to about 30% to 50% of the sniff interval (e.g. ATS562=5, see section 6.2)
- Keep the attempt parameter at minimum (ATS561=2)

In addition, if more efforts can be spent on low power optimisation:

- Characterise the expected data: amount, timing, maximum acceptable delay
- Derive maximum SSR latencies and SSR timeouts
- Derive a sniff interval which is a whole numbered common factor of SSR latency
- Use delayed sniff mode requests (S364>0) only if the remote's end sniff parameters are not suitable for the application. Avoid this feature if possible (it is experimental and has not been tested against other devices than BTM41x)
- Verify actual parameters using ATI commands (see examples)
- Optimise settings iteratively by doing current measurements, as proposed by the examples of this document

6 Appendix

6.1 Literature References

[1] Sniff and Sniff Sub-rating Modes White Paper, 2008-08-14, V10r00, Bluetooth SIG / BARB
https://www.bluetooth.org/DocMan/handlers/DownloadDoc.ashx?doc_id=125640

6.2 Known Issues

- S561, S562: An issue was observed with firmware v16.1.3.1 (which was used for this document): Sniff parameters "Attempt" (S561) and "Timeout" (S562) result in double of the expected time. For example if set to 30, the actual time will be 60 ms instead of 30 ms. [Ref. 3-4]

6.3 S-Register and ATI Reference

This section contains a reference list of S-Registers and ATI commands which are relevant to power configuration.

Table 6-1: S-Registers for low power configuration

Register	Deflt.	Range	Category	Description
S348	0	0..170	SSR	SSR (maximum) remote interval in units of 0.1s. Refer to Sniff Sub-Rating (SSR) Register Mapping (S348..S350) and to Table 6-4.
S349	0	0..170	SSR	SSR (minimum) remote timeout in units of 0.1s. Refer to section Sniff Sub-Rating (SSR) Register Mapping (S348..S350) and to Table 6-4.
S350	0	0..170	SSR	SSR (minimum) local timeout in units of 0.1s. Refer to section Sniff Sub-Rating (SSR) Register Mapping (S348..S350) and to Table 6-4.
S364	0	0..31	lpp_ table	Duration of initial power mode in seconds (link policy power table) 0=indefinite (=disable advanced sniff mode configuration)
S365	0	0..1	lpp_ table	Set initial power mode to active (link policy power table) 0 = passive mode 1 = active mode Register applies only if S364 > 0. If Sniff mode is disabled (S561=0), the second row of the link policy power table will be passive mode for indefinite duration.
S508	640	11..255 0	Scan	Page Scan Interval in milliseconds. Minimum is 11.25 ms so 10/11 ms will give 11.25 ms
S509	160	11..255 0	Scan	Page Scan Window in milliseconds. Minimum is 11.25 ms so 10/11 ms will give 11.25 ms
S510	640	11..255 0	Scan	Inquiry Scan Interval in milliseconds. Minimum is 11.25 ms so 10/11 ms will give 11.25 ms
S511	160	11..255 0	Scan	Inquiry Scan Window in milliseconds. Minimum is 11.25 ms so 10/11 ms will give 11.25 ms
S512	1	0..7	Scan	Specify power up state. 0: AT+BTO is required to enable activity. 1: Proceeds as if AT+BTO was entered. 2: Discoverable only, similar to issuing AT+BTQ.

Register	Deflt.	Range	Category	Description
				3: Connectable but not discoverable e.g. AT+BTG 4: Connectable and discoverable e.g. AT+BTP. 5: Like 2, but all UART RX traffic is discarded in absence of a connection while DSR is asserted. If DSR is not asserted, then it behaves exactly as per mode 2. 6: Like 3, but all UART RX traffic is discarded in absence of a connection while DSR is asserted. If DSR is not asserted, then it behaves exactly as per mode 3. 7: Like 4, but all UART RX traffic is discarded in absence of a connection while DSR is asserted. If DSR is not asserted, then it behaves exactly as per mode 4. **Note:** By implication, a change to this only displays after a power cycle AND if AT&W was issued before the power cycle.
S561	0	0..1600	Sniff Mode	Sniff Mode Attempt Time (N) in units of milliseconds. See section 6.3.1 and to Table 6-3 for mapping details.
S562	0	0..1600	Sniff mode	Sniff Mode Timeout Time (T) in units of milliseconds. See section 6.3.1 and to Table 6-3 for mapping details.
S563	0	0..1600	Sniff mode	Sniff Mode Minimum Interval in units of milliseconds. See section 6.3.1 and to Table 6-3 for mapping details. This register doesn't have any impact (BTM41x only supports single point connections). But firmware still requires this register to be set to a value less than S564.
S564	0	0..1600	Sniff mode	Sniff Mode Maximum Interval (M) in units of milliseconds. Refer to section 6.3.1 and to Table 6-3 for mapping details. Between two BTM41x: when requesting sniff mode, this becomes the actual sniff interval. Although S563 doesn't have an impact, firmware requires S564 to be greater than S563.

Table 6-2: ATI commands for low power configuration

Command	Description
ATI27	Current scan state: 0 = not discoverable or connectable (not scanning) 1 = discoverable (inquiry scanning) 2 = connectable (page scanning) 3 = discoverable and connectable (inquiry and page scanning)
ATI43	Query current device role of SPP link: 'M' = master; 'S' = slave; ERROR 14 = incorrect mode (no SPP link); Normally, the initiating device becomes master of a link and the accepting device becomes the slave. If ATI44 returns the unexpected role, most likely a role change has occurred.
ATI44	Query current power mode of SPP link (active / sniff / passive) and sniff interval Response: "<power_mode>,<sniff_interval_**in_slots**_decimal>" <power mode>: 0 = active (highest power consumption, lowest latency/responsiveness) 1 = sniff mode (power consumption and latency depend on sniff interval) 2 = passive (the device will not initiate a change of the power mode)

Command	Description
ATI45	Query current sniff sub-rating (SSR) parameters of SPP link, **in slots** (1 slot = 0.625 ms) Response: "<flag>, ,<ri>,<lto>,<rto>" <flag>: 1 = SSR active / 0 = SSR not active = "local SSR interval", decimal integer, slots <ri> = "remote SSR interval", decimal integer, slots <lto> = "local timeout" , decimal integer, slots time before changing from sniff mode to SSR when no data being transmitted <rto> = "remote timeout", decimal integer, slots time before changing from sniff mode to SSR when no data being transmitted.
ATI46	Query current link policy power table Response for each row: "[<index>] <mode>,<time>,<min_int>,<max_int>,<attempt>,<timeout>" <index>: row index, starting with 0 <mode>: power mode, 0=active, 1=sniff, 2=passive <time>: duration of current row in s (switching to next row after this timeout) <min_int>, <max_int>: sniff mode intervals **in slots**, (S563 / S564, 'M') <attempt>: number of active **slots** at beginning of sniff interval (S561, 'N') <timeout>: number of additional active **slots** (S562, 'T') if data exchanged
ATI144	Like ATI44, but sniff interval **in milliseconds** instead of slots. Rounding indicated by '!'
ATI145	Like ATI45, but all values **in milliseconds** instead of slots. Rounding indicated by '!'
ATI146	Like ATI46, but all values **in milliseconds** instead of slots. Rounding indicated by '!'

6.3.1 Sniff Mode Register Mapping (S561..S564)

The sniff mode configuration registers S561, S562, S563 and S364 have been assigned a mapping according to Table 6-3. A value is written in units of 1 ms. Although any value in the range [0..1600] ms is accepted, internally any written value is rounded to the nearest of column "Read (ms)". Hence, it is recommended to write only values of the "Read (ms)" column in order to prevent confusion. The resulting number of slots and the resulting actual time is shown in Table 6-3 as well. The duration of a Bluetooth slot is fixed at 0.625 ms. To convert a value from milliseconds to slots, multiply the value by 1.6.

Note: An issue was observed with S561 and S562. Please refer to section 6.2.

6.3.2 Sniff Sub-Rating (SSR) Register Mapping (S348..S350)

The sniff sub-rating (SSR) configuration registers S348, S349 and S350 have been assigned a mapping according to Table 6-4 ***See Section 6.2***

Table 6-4. A value is written in units of 0.1s. Although any value in the range [0..170] is accepted, written values are internally rounded to the nearest of column "Read (ms)". Laird recommends you only write values of the "Read (ms)" column in order to prevent confusion. The resulting number of slots and the resulting actual time is shown in Table 6-4 as well. The duration of a Bluetooth slot is fixed at 0.625 ms. To convert a value from milliseconds to slots, multiply the value by 1.6.

Table 6-3: Sniff register mapping S [561…564]

Write (ms)	Read (ms)	No. of slots	actual ms *
[0, 1]	0	0	0
[2, 3]	2	4	2.5
[4, 6]	5	8	5
[7, 8]	7	12	7.5
[95, 149]	100	160	100
[150, 249]	200	320	200
[250, 349]	300	480	300
[350, 449]	400	640	400

[9, 11]	10	16	10	[450, 549]	500	800	500
[12, 13]	12	20	12.5	[550, 649]	600	960	600
[14, 16]	15	24	15	[650, 749]	700	1120	700
[17, 18]	17	28	17.5	[750, 849]	800	1280	800
[19, 24]	20	32	20	[850, 949]	900	1440	900
[25, 34]	30	48	30	[950, 1049]	1000	1600	1000
[35, 44]	40	64	40	[1050, 1149]	1100	1760	1100
[45, 54]	50	80	50	[1150, 1249]	1200	1920	1200
[55, 64]	60	96	60	[1250, 1349]	1300	2080	1300
[65, 74]	70	112	70	[1350, 1449]	1400	2240	1400
[75, 84]	80	128	80	[1450, 1549]	1500	2400	1500
[85, 94]	90	144	90	[1550,1600]	1600	2560	1600

**See Section 6.2*

Table 6-4: Sniff sub-rating (SSR) register mapping S [348…350]

Write (0.1 s)	Read (0.1 s)	No. of slots	actual s	Write (0.1 s)	Read (0.1 s)	No. of slots	Actual s
[0]	0	0	0	[38,42]	40	6400	4
[1]	1	160	0,1	[43,47]	45	7200	4,5
[2]	2	320	0,2	[48,52]	50	8000	5
[3]	3	480	0,3	[53,57]	55	8800	5,5
[4]	4	640	0,4	[58,64]	60	9600	6
[5]	5	800	0,5	[65,74]	70	11200	7
[6]	6	960	0,6	[75,84]	80	12800	8
[7]	7	1120	0,7	[85,94]	90	14400	9
[8]	8	1280	0,8	[95,104]	100	16000	10
[9]	9	1440	0,9	[105,114]	110	17600	11
[10,12]	10	1600	1	[115,124]	120	19200	12
[13,17]	15	2400	1,5	[125,134]	130	20800	13
[18,22]	20	3200	2	[135,144]	140	22400	14
[23,27]	25	4000	2,5	[145,154]	150	24000	15
[28,32]	30	4800	3	[155,164]	160	25600	16
[33,37]	35	5600	3,5	[165,170]	170	27200	17

6.4 Examples

6.4.1 Screenshots and Measurements

The digital lines RX, TX and DCD refer to the UART of device A in all of the following oscilloscope screenshots. For device A (blue), 1mV = 1mA. The amplitude of device B was scaled to present the same amplitude as device A. Screenshots where the absolute value of device B seems to vary can be explained by an increasingly drained battery that was used to power device B. The focus of this document is investigation of current patterns rather than absolute current measurements, so this effect is regarded as unimportant.

6.4.2 Discoverable / Connectable

When not discoverable and not connectable and when no command is entered, BTM41x draws current as shown in Figure 7. This is the factory default state after powering the module. In this mode it is only possible to initiate inquiries, pairing or connections (which draw current, not shown). Neither incoming connection nor pairing will work, and the device won't be found by other inquiring devices either.

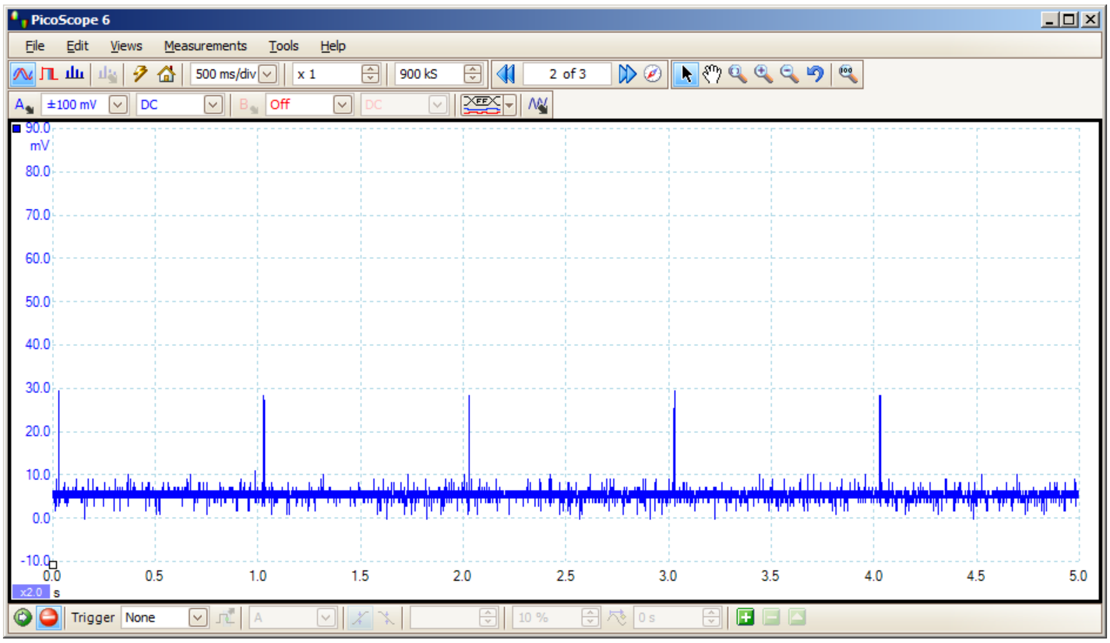

Figure 7: not connectable, not discoverable (default state or AT+BTX or S512=1)

Current patterns for a BTM41x in discoverable and connectable mode (AT+BTP) are shown in Figure 8. The default parameters are 160 ms for the scan windows (S509, S511) and 640 ms for the scan intervals (S508, S510). The first half of the activity phase is spend for inquiry scanning, the second half for page scanning. The total length of the scanning phase is 320 ms. Hence, 320 ms are remaining for the inactive phase before the next scan activity begins.

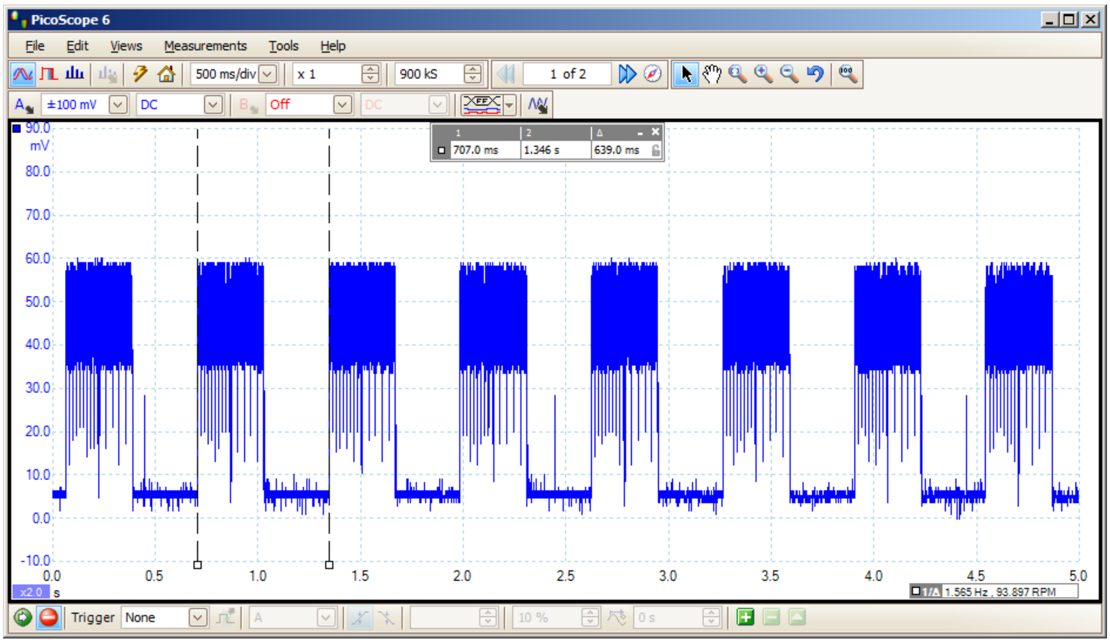

Figure 8: discoverable and connectable (AT+BTP or ATS512=4)

AT+BTP: [508,509,510,511] = 640,160,640,160

When entering discoverable only (AT+BTQ, Figure 9), the resulting activity phase is only half as long as before, because now the baseband doesn't scan for paging any more. The same effect is visible when entering connectable only (AT+BTG, Figure 10).

Conclusion: with default scan parameters, half of the energy can be saved by disabling unnecessary scanning. For example, after a device has paired, if it is only waiting for incoming connections, inquiry scanning (discoverable) can be disabled.

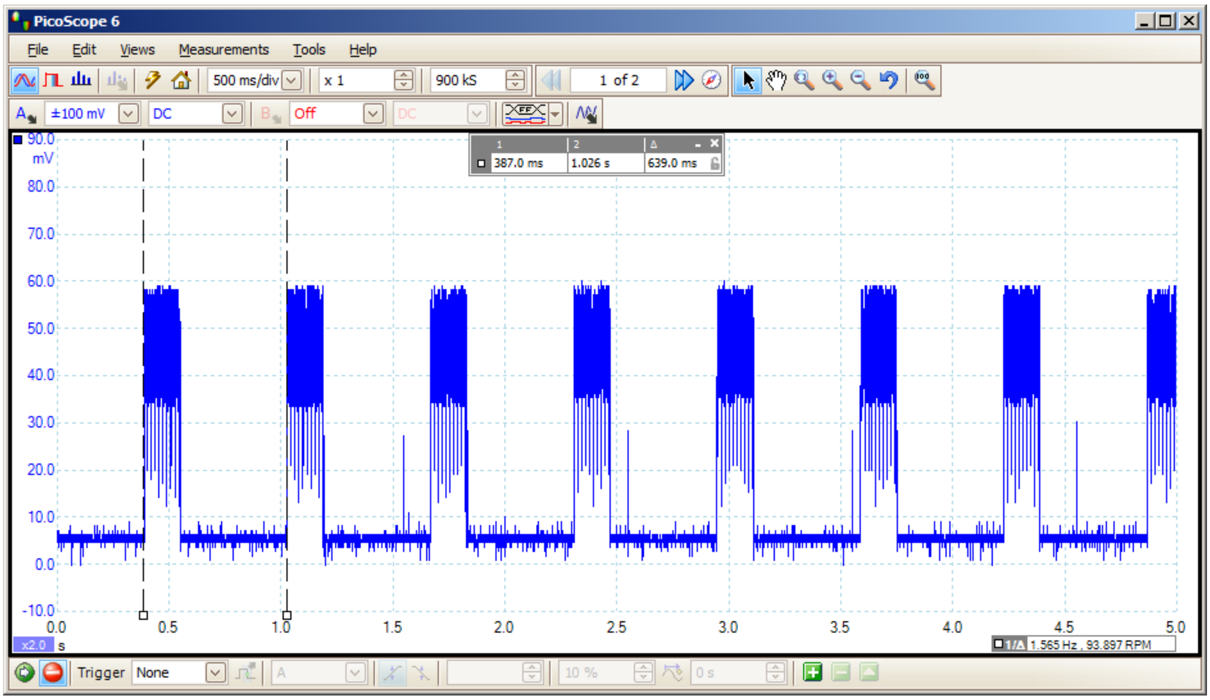

Figure 9: discoverable (AT+BTQ or ATS512=2)

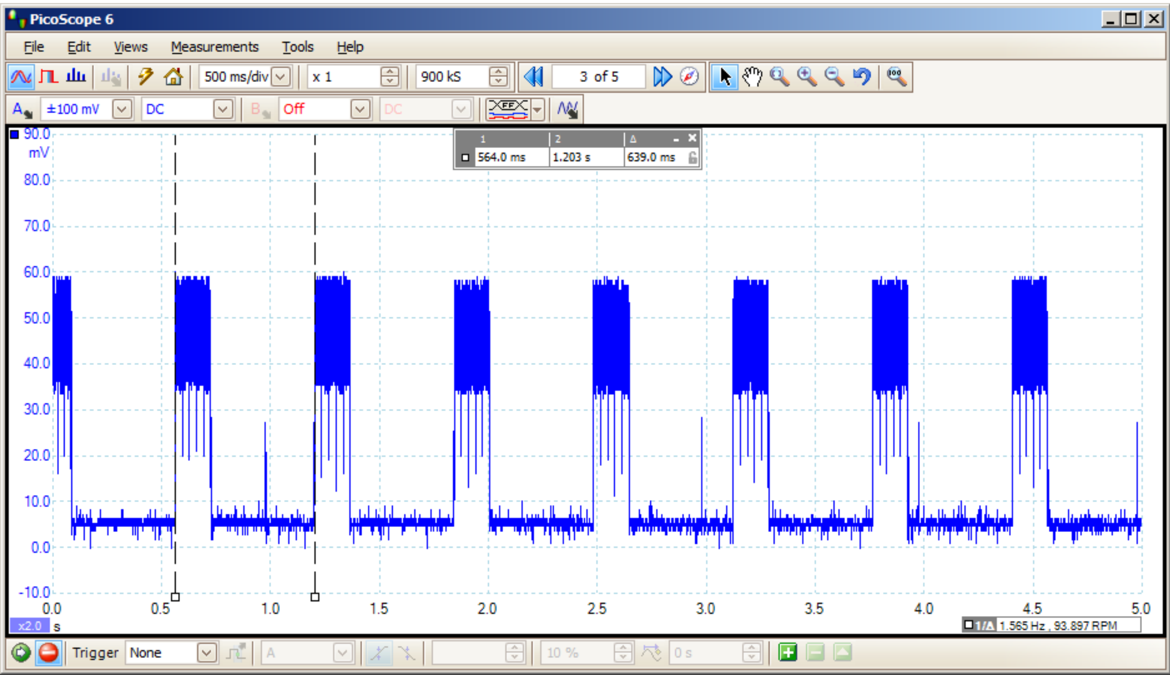

Figure 10: connectable (AT+BTG or ATS512=3)

Scan parameters (S508…S511) allow a variation of scan window and interval. The following examples investigate how these variations affect current patterns. To begin with, we reduce the page scan window to 50 ms (ATS509=50) while keeping the page scan interval at default (ATS508=640). See Figure 11. Here, energy use is reduced but the time required for other devices to initiate a connection is increased.

If connection establishment can be delayed to save power, we can go further by increasing the scan interval, for example, to 1500 ms (ATS508=1500). The result is shown in Figure 12.

Finally, the most extreme example: page scan window = 11 ms (ATS509=11, minimum) and page scan interval = 2550 ms (ATS508=2550, maximum). The result is shown in Figure 13.

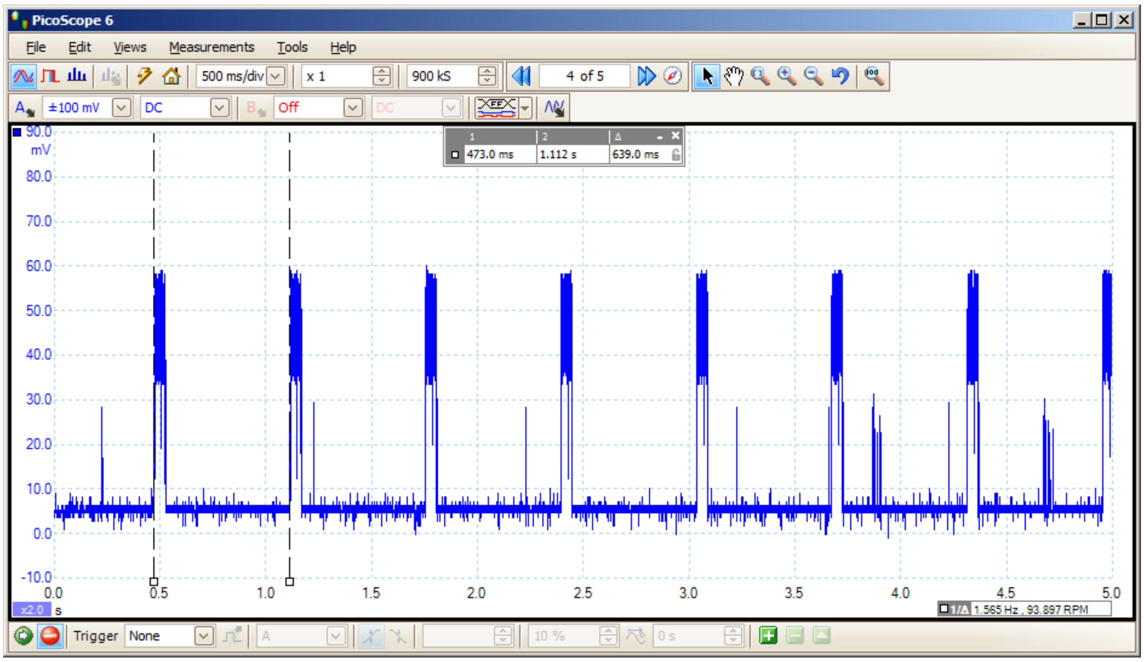

Figure 11: connectable, page scanning window=50 ms (ATS509=50)

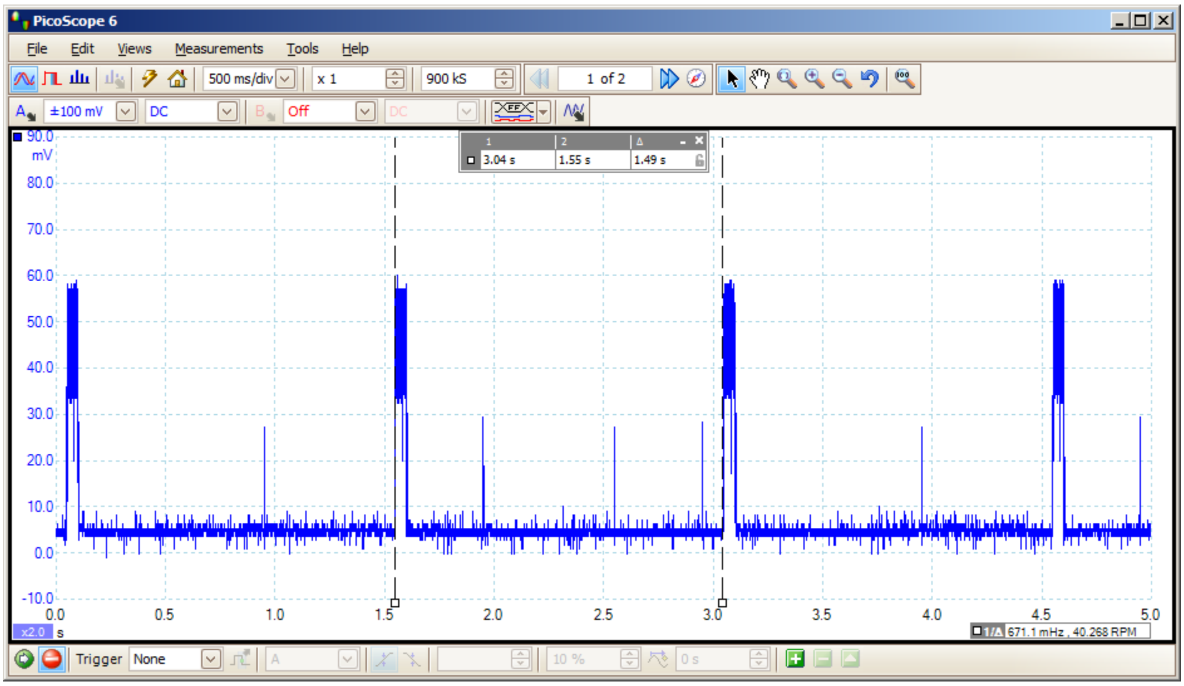

Figure 12: connectable, page scanning window=50 ms (ATS509=50), page scan interval=1500 ms (ATS508=1500)

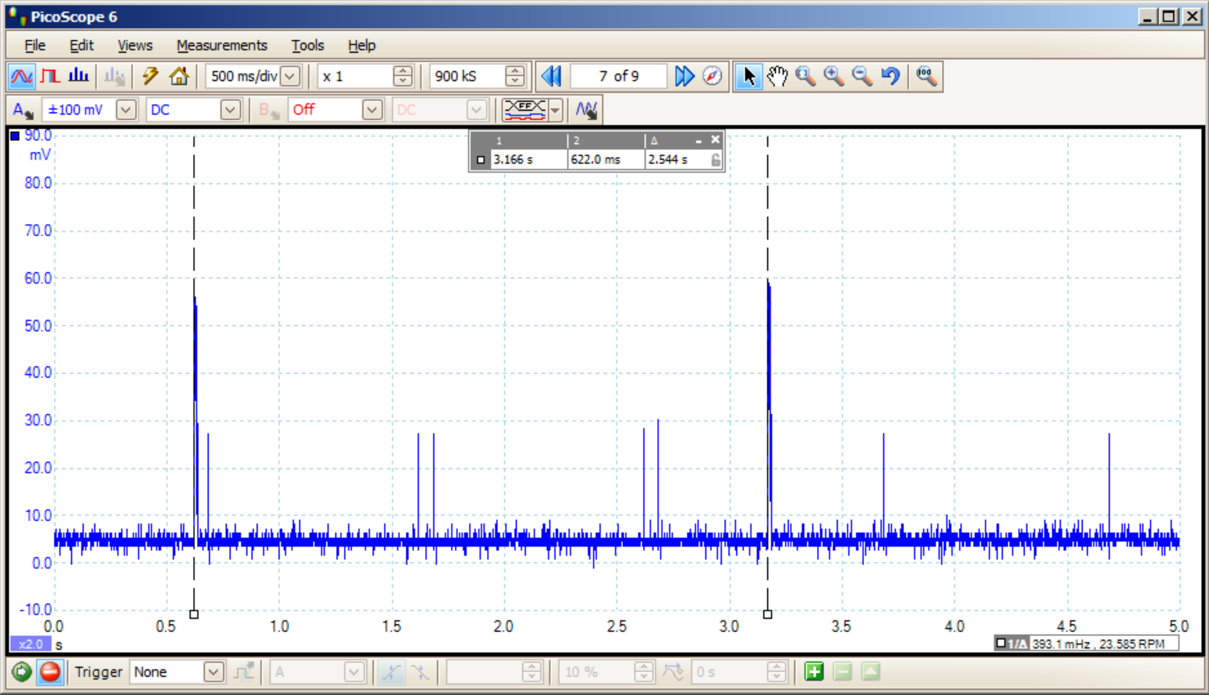

Figure 13: connectable, page scanning window=11 ms (ATS509=11), page scan interval=2550 ms (ATS508=2550)

The last group of examples demonstrate a variation of the default parameters for discoverable and connectable. First, we set the page scan window to 50 ms as in the previous example. But now we look at a zoom of the activity phase (Figure 14): A division is detected at the last quarter. The first part's length is 160 ms and the second part's length is 50 ms. This shows that inquiry scanning (a 160 ms window) occupies the first part of the activity phase and page scanning (50 ms) follows immediately.

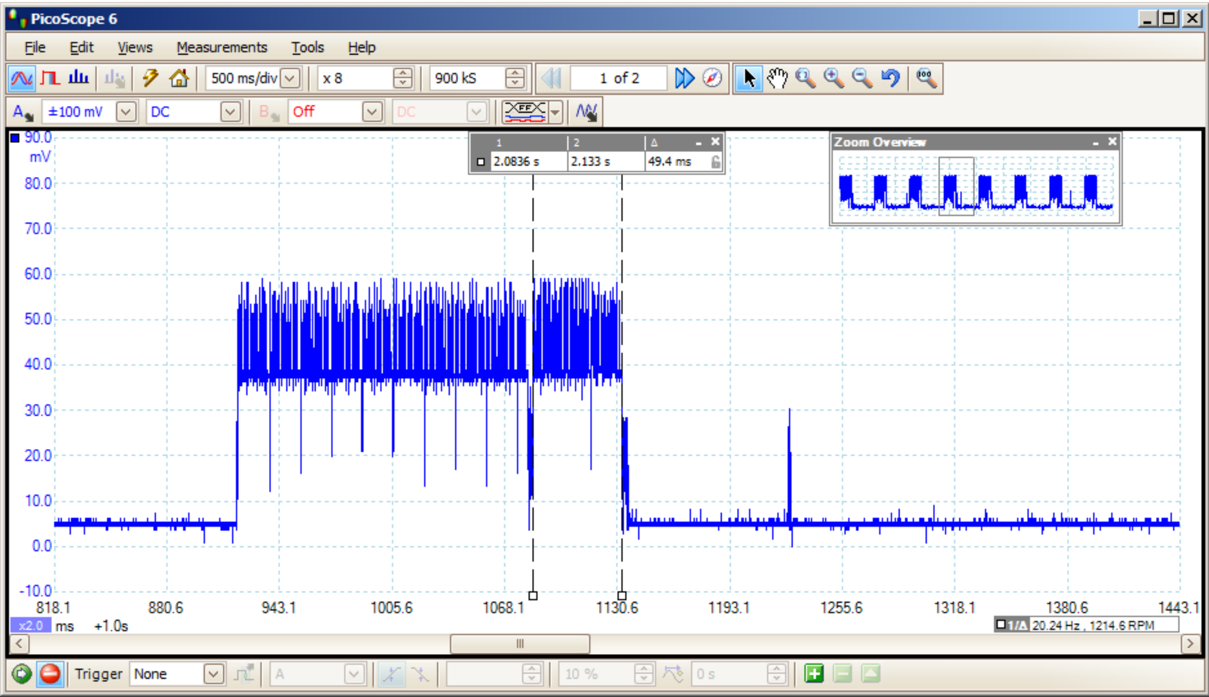

Figure 14: discoverable and connectable, inquiry scanning=160 ms, page scanning=50 ms (ATS509=50)

It would still be interesting to see what happens if the intervals for page and inquiry scanning are different. We set the page scanning interval to 1000 ms (ATS508=1000). We can still identify page scanning by the 50 ms window. The result is the following (Figure 15): the baseband adheres to our settings and does the page scanning with intervals of 1 second. If at the beginning of the next activity phase of one scan type the other is already active, then the start of the scheduled scan starts immediately after the other type has finished. At 3.5 seconds, as page scanning was active at the scheduled beginning of inquiry scanning, the latter was delayed until page scanning was finished.

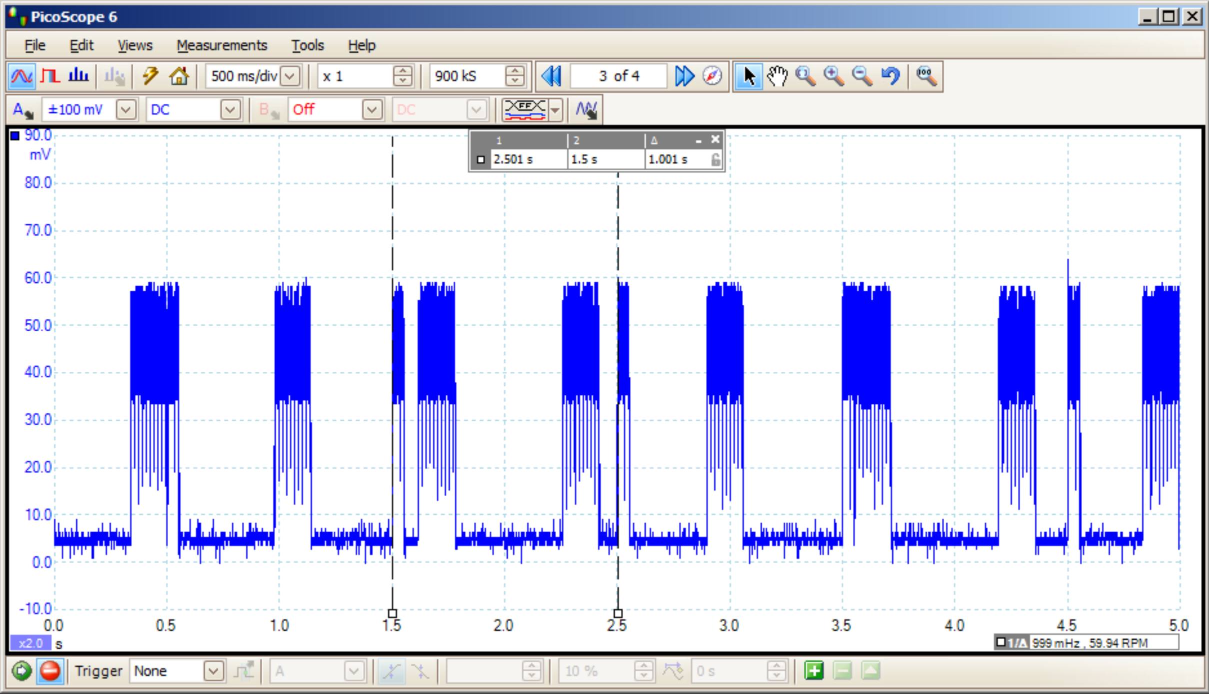

Figure 15: mixed intervals: inquiry scanning 160/640 ms, page scanning 50/1000 ms

6.4.3 Active Mode

This example shows an SPP link between two BTM41x in active mode. Active mode is the factory default for a connection (Figure 16).

The link was initiated by Device A, which is the master (ATI43, Table 6-5) as expected. If ATI43 would indicate 'S' (slave) on the initiator, this would imply a role change having occurred, but this is not the case here. A role change was observed when initiating an SPP link to other devices such as Windows PC.

The zoomed view (Figure 17) shows that the master is polling the slave every 18 TX/RX slot pairs (22.5 ms). In contrast, the slave listens for the master at each slot pair (every 1.25 ms). If no data is being exchanged, power is significantly wasted. Even the master could extend its polling interval when no data is being exchanged.

In the case of data exchange (Figure 18), the master is active more often. Thus the slave is not wasting power listening to the master because data is actually exchanged. Active mode offers the best responsiveness and lowest latency at the cost of wasted power when data is not being transferred.

Table 6-5: Configuration for active mode (default)

	S-Register/ATI	Device A (blue)	Device B (red)
Sniff	S 561, 562, 563, 564	[0, 0, 0, 2] - *disabled*	[0, 0, 0, 2] - *disabled*
SSR	S 348, 349, 350	[0, 0, 0] - *disabled*	[0, 0, 0] - *disabled*
Role	ATI43	M	S
Power mode, interval	ATI144	0,0	0,0
SSR parameters	ATI145	0,0,0,0,0	0,0,0,0,0
Link policy power table	ATI146	[0] 2,0,0,0,0,0	[0] 2,0,0,0,0,0

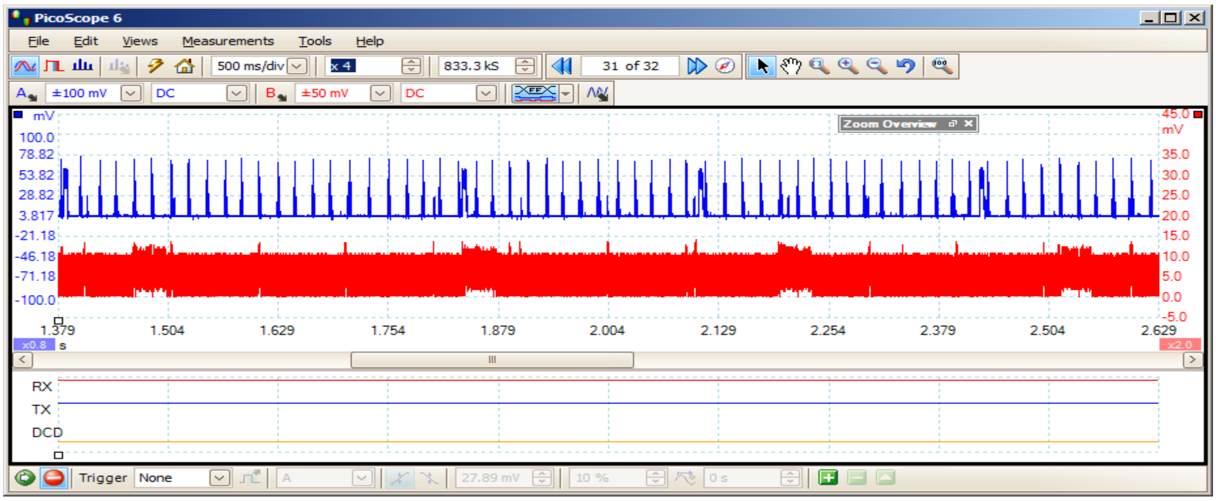

Figure 16: Active mode - master (blue) and slave (red) current, no data exchange

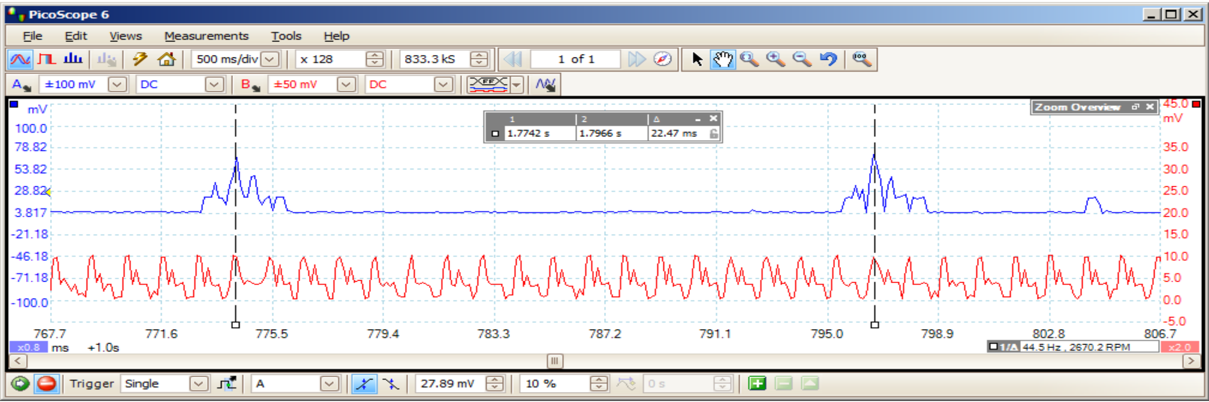

Figure 17: Active mode - master (blue) and slave (red) current patterns, zoomed view

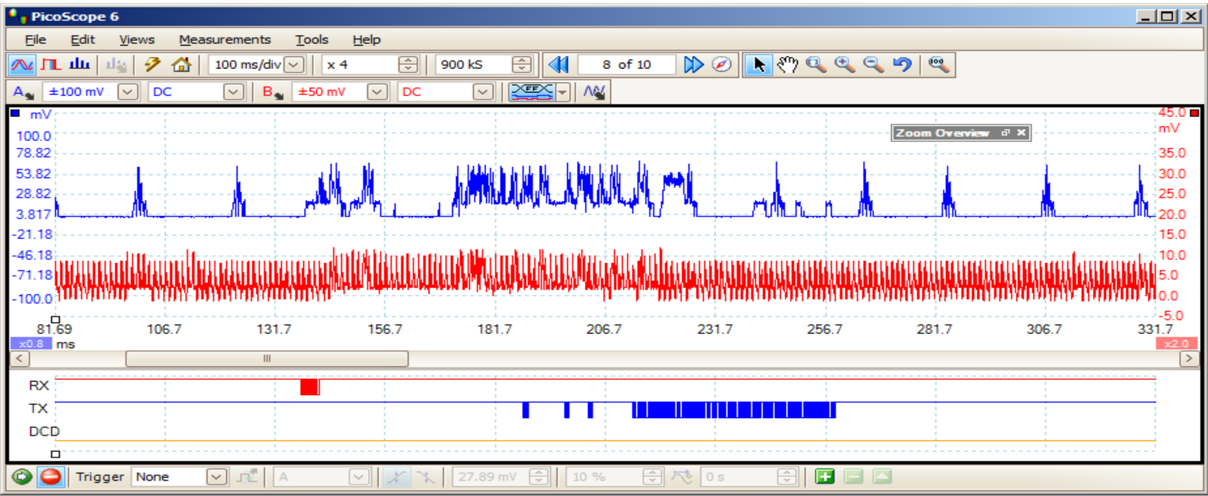

Figure 18: Active mode with some data exchanged

6.4.4 Sniff Mode, Basic Configuration

Sniff mode minimises power consumption when no data is transferred while increasing the latency of transmitted data.

6.4.4.1 Sniff Interval

In the first example (Table 6-6 / Figure 19), sniff mode is only enabled on device A. The resulting sniff interval is 100 ms (ATI144). The baseband enters sniff mode shortly after the connection is established (DCD transition).

Table 6-6: Sniff mode enabled on device A only

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 90, 100] - *enabled*	[0, 0, 0, 2] – *disabled*
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,100	1,100
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 1,0,90,100,2!,2!	[0] 2,0,0,0,0,0

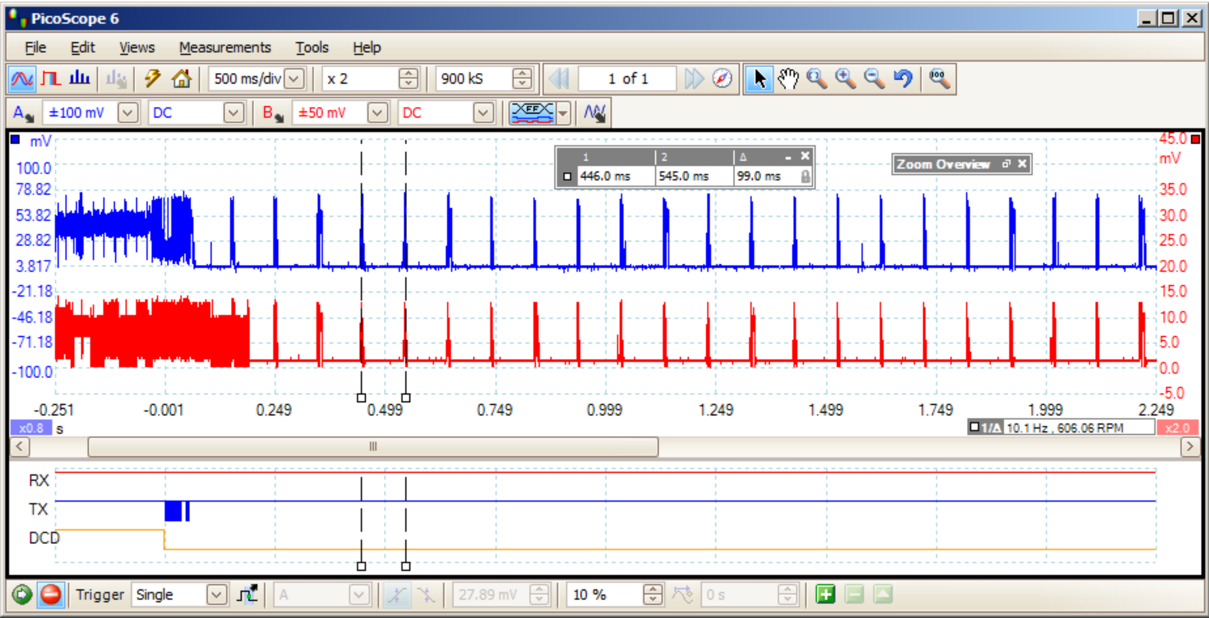

Figure 19: Sniff mode enabled on device A (blue) only

The next example (Table 6-7/ Figure 20) shows sniff mode enabled only on device B. The (max) sniff interval chosen is 200 ms (S564). Sniff mode is entered shortly after the link is established. The resulting sniff interval is 200 ms (ATI144), as expected.

Table 6-7: Sniff mode, enabled on device B only

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[0, 0, 0, 2] – *disabled*	[2, 2, 100, 200] – *enabled*
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,200	1,200
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 2,0,0,0,0,0	[0] 1,0,100,200,2!,2!

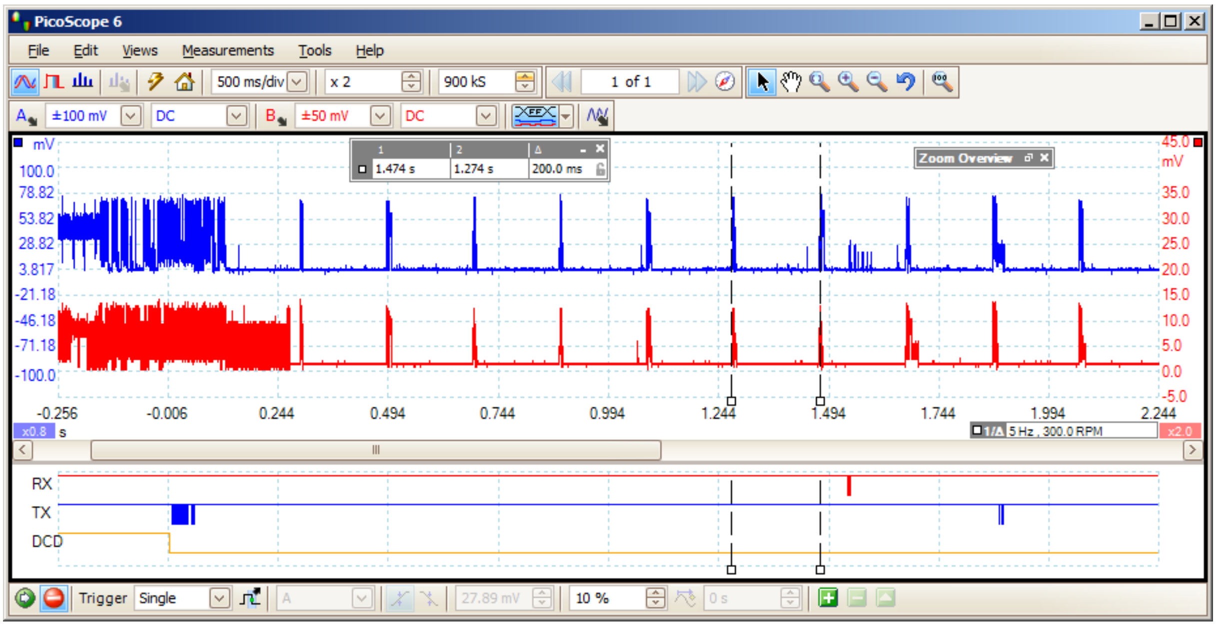

Figure 20: Sniff mode, enabled on device B only

Conclusion: If sniff mode is enabled at one end only, then we know that the configured sniff interval applies to the link.

Now we enable sniff mode on both ends in order to see what happens in this scenario. We choose a (maximum) sniff interval of 50 ms for device A and 200 ms for device B. This allows us to identify via current measurements which device's parameters are applied to the link. We could also poll ATI144 / ATI44 to query the actual current sniff interval. Figure 21 shows a sniff interval of 50 ms. ATI144 (Table 6-8) confirms 50 ms. Then, about five seconds after the connection is established, the sniff interval changes (Figure 22). The new interval is 200 ms which was obviously set in device B. ATI144 now returns "1,200" (1=sniff mode, 200=interval in ms).

Another effect can be seen here: changing sniff mode parameters always has to pass through active mode. That explains the short dense phase at second 5 in Figure 22.

Conclusion: If both ends have sniff mode parameters set, we cannot assume the existence of particular sniff parameters on the link. The final decision is made by the baseband and we can only query the current sniff interval by ATI144/ATI44. The maximum sniff interval (S564) obviously applies to the link. The minimum sniff interval (S563) doesn't impact two BTM41x units so it doesn't matter if the max-min range of both ends overlaps. In our example, it doesn't overlap.

Table 6-8: Sniff mode enabled on device A and B, after connection established

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 40, 50] – *enabled*	[2, 2, 100, 200] – *enabled*
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,50	1,50
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 1,0,40,50,2!,2!	[0] 1,0,100,200,2!,2!

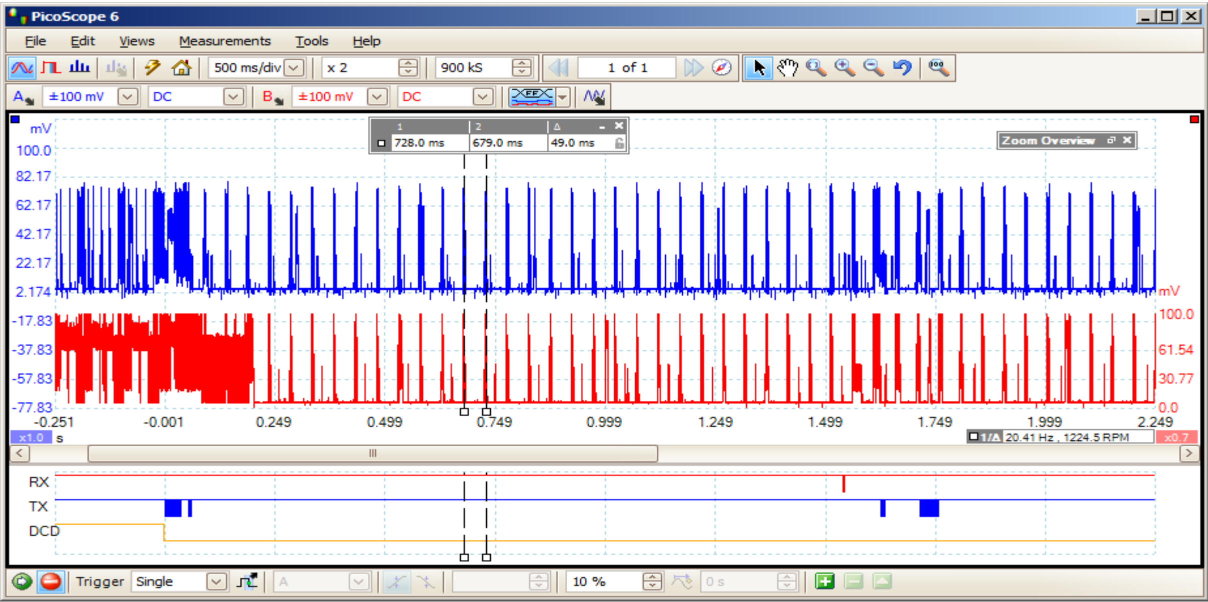

Figure 21: Sniff mode enabled on device A and B, after connection established

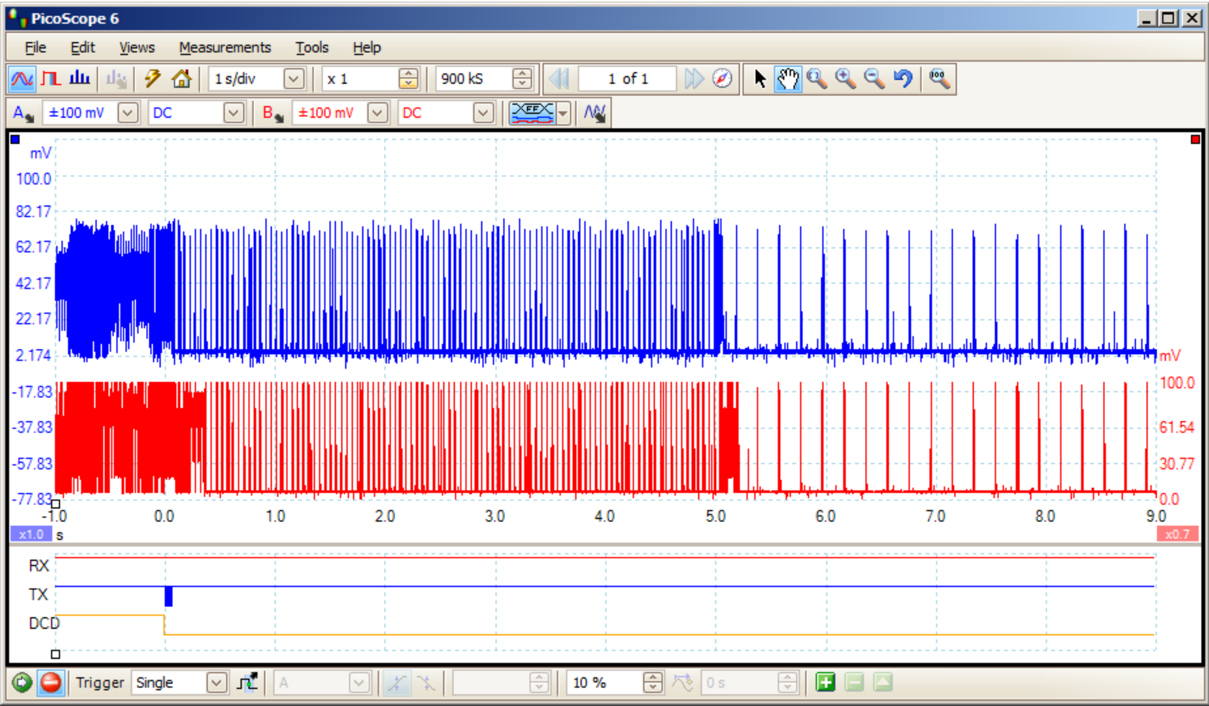

Figure 22: Sniff mode enabled on both ends, change of sniff interval after 5s

As a last example for sniff interval, let's swap master and slave while keeping all other parameters the same. Between two BTM41x this swap can be easily achieved, just by initiating from the other end (device B here). With other devices this may not be possible. For example, a role change was observed when initiating a connection (SPP) from BTM41x to a Windows PC.

The outcome is documented by Figure 23 and Table 6-9. After five seconds of sniff mode with 200 ms (device B, master) interval, the sniff interval is changed to 50 ms (device A, slave) by passing through active mode. ATI144 would respond with "1,50", if queried after the change.

Considering a similar observation of Figure 22, one could conclude that always the master parameter applies for five seconds and then the slave. At this point it must be mentioned that the AT–command layer doesn't have any direct control or any visibility of these baseband algorithms. So it may well be, but there is no guarantee that this observed behaviour will always occur.

Table 6-9: Master and slave swapped, ATI144 captured within the first 5 seconds of the connection

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 40, 50] – *enabled*	[2, 2, 100, 200] – *enabled*
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	S	M
pwr.mode/intv.	ATI144	1,200	1,200
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 1,0,40,50,2!,2!	[0] 1,0,100,200,2!,2!

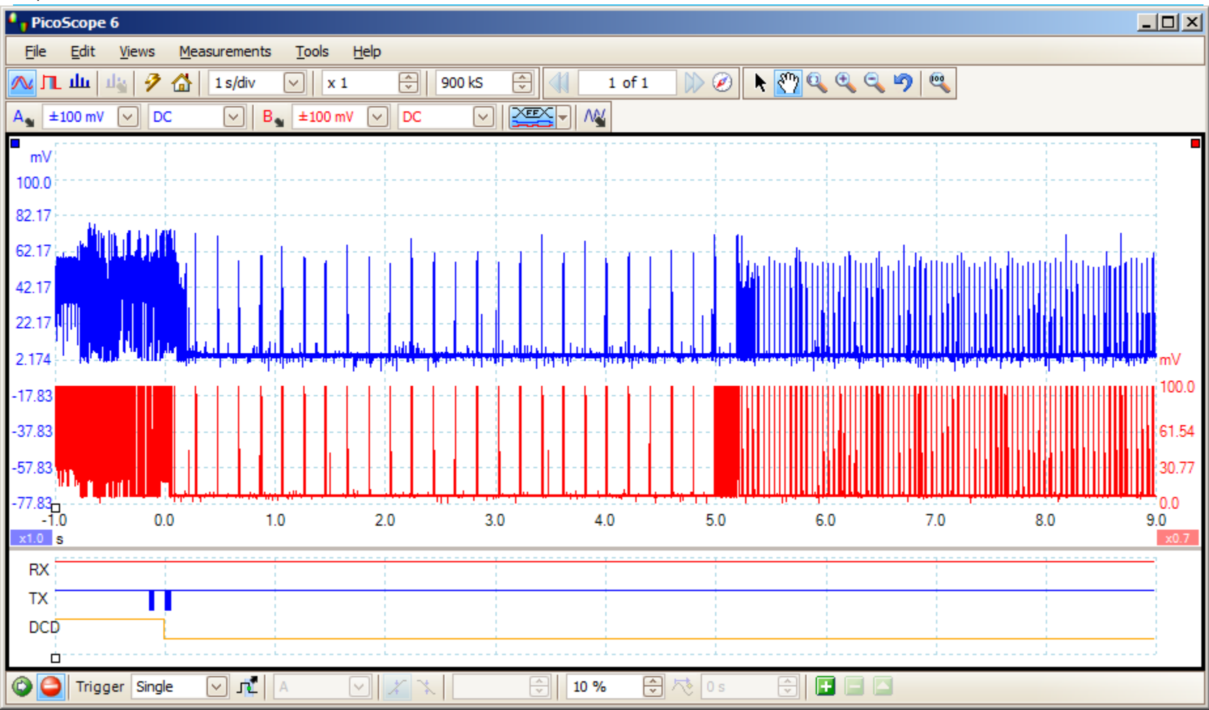

Figure 23: Master and slave swapped

6.4.5 Delayed Sniff Mode (Link Policy Power Table)

The link policy power table is used to influence which device's sniff interval remains on the link.

This is useful if the application has control over only one end. This feature is experimental and has not been tested against other devices yet.

If both ends are BTM41x radios, Laird recommends you enable sniff parameters on one end only. This ensures that only those parameters apply to the link and delayed sniff mode is not needed.

One important observation is the "5s effect". As seen in previous examples, something seems to happen at 5 seconds after connection establishment. For the link policy power table (lpp_table) a duration of less than five seconds (S364 <= 5) doesn't seem to have an impact within this period. After five seconds we see the expected result.

For a duration of e.g. 8 seconds (S364=8) the timing works as expected. Please refer to the example below.

6.4.5.1 Passive Mode (S365=0)

This section presents examples with "passive" mode in the link policy power table (lpp_table).

6.4.5.1.1 One End

First we enable a duration of 1 second on device A (S364=1, Table 4-1). Passive mode is set by S365=0 (default). Sniff mode parameters of previous examples are kept here: sniff interval = 50 ms on device A and 200 ms on device B.

Querying the lpp_table (ATI44 or ATI144) returns two rows. Row [0] contains just passive mode ('2') for 1 second ('1'). Sniff parameters are set to '0' by AT firmware. Row [1] contains sniff mode ('1'), indefinite duration ('0') and sniff parameters as configured by S563, S564, S561, S562 (in this order, see Table 4-1).

Table 6-10: lpp_table - device A passive mode, 1s

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 40, 50]	[2, 2, 100, 200]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,50 (later than 5.5 s)	1,50 (later than 5.5 s)
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 2,1,0,0,0,0 [1] 1,0,40,50,2!,2!	[0] 1,0,100,200,2!,2!
Duration/active	S 364, 365	[1, 0]	[0, 0]

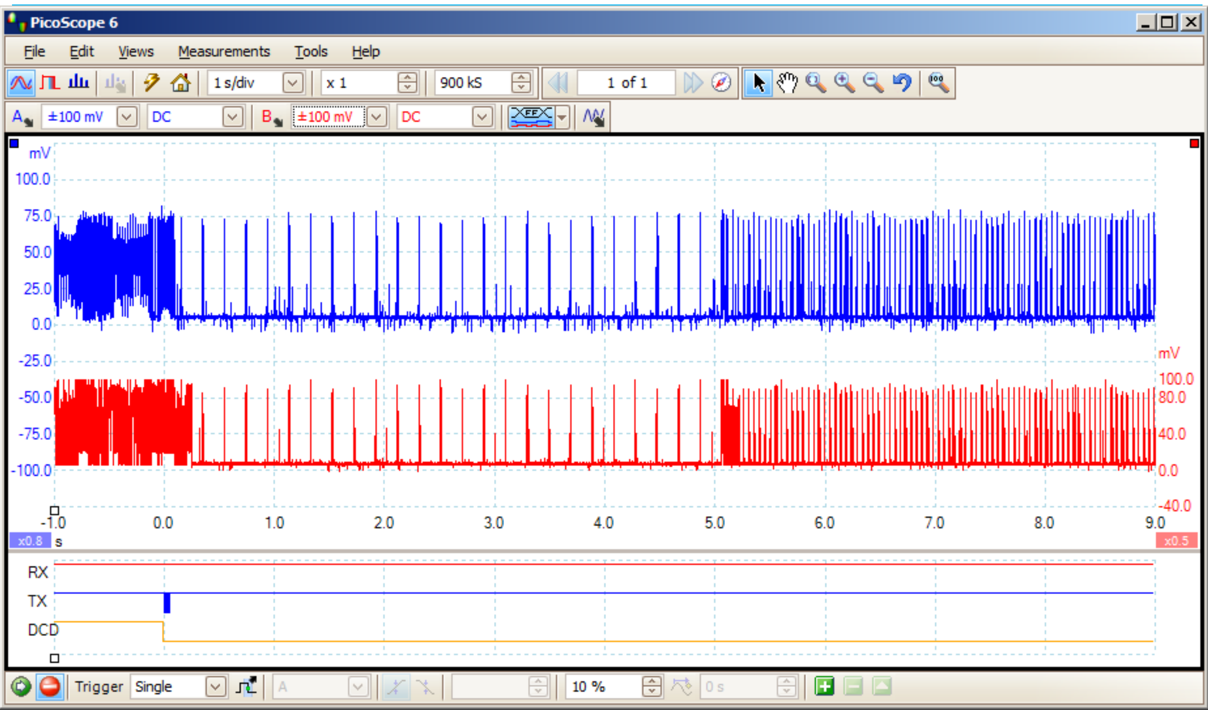

Figure 24: lpp_table – device A, passive mode, 1s

The lpp_table is meant to delay the local sniff mode request so that local sniff parameters persist on the link. As shown in Figure 24, device B immediately requests sniff mode with its 200 ms interval. After five seconds (instead of one expected), we see a change of the sniff interval to 50 ms, coming from device A.

Conclusion: the intention of a persisting 50 ms sniff interval succeeds not after 1 second but delayed by the "5 second effect".

Now we check if it the role (master/slave) makes any difference. This time we initiate the link from device B. Table 6-11 shows the usual parameters, with 'M' and 'S' swapped.

Table 6-11: lpp_table - device A passive mode, 1s, slave

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 40, 50]	[2, 2, 100, 200]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	S	M
pwr.mode/intv.	ATI144	1,50 (later than 5.5 s)	1,50 (later than 5.5 s)
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0

		DevA (blue)	DevB (red)
lp_table	ATI146	[0] 2,1,0,0,0,0 [1] 1,0,40,50,2!,2!	[0] 1,0,100,200,2!,2!
Duration/active	S 364, 365	[1, 0]	[0, 0]

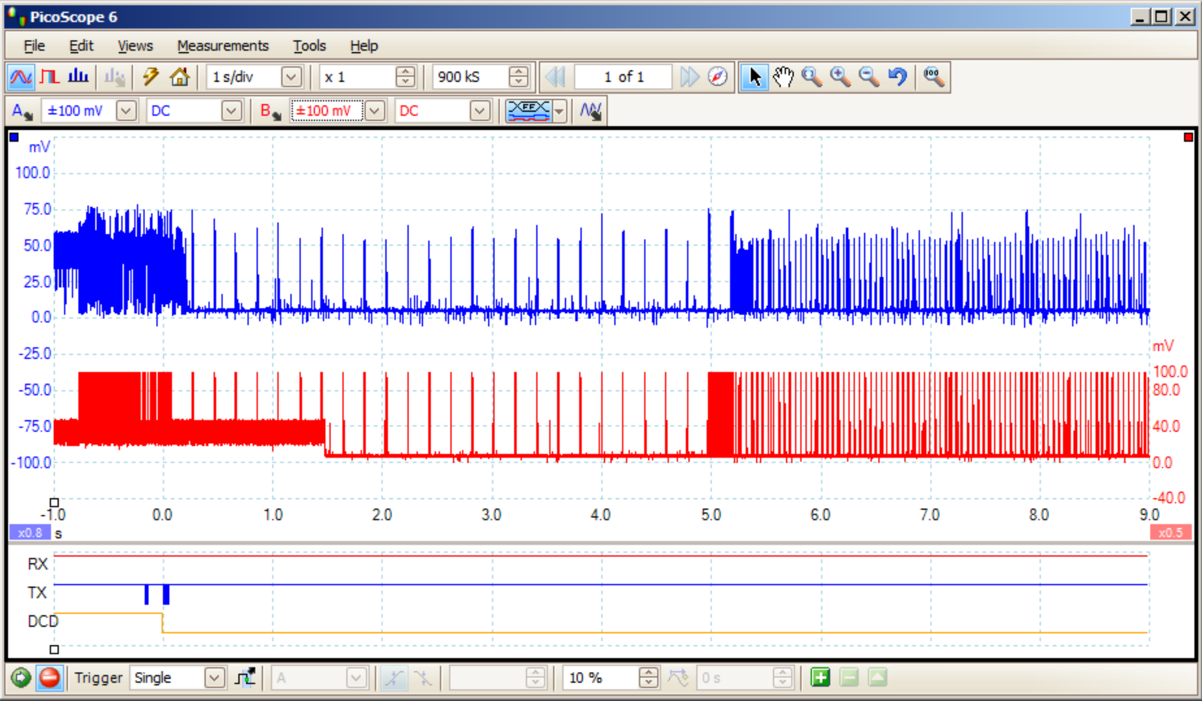

Figure 25: lpp_table - device A passive mode, 1s, slave

According to Figure 25, the remaining sniff interval is 50 ms, coming from device A. The five second effect is present as well. The result in terms of current patterns is identical to Figure 24.

Conclusion: For delayed sniff mode enabled on one end with passive mode, the result is **not** affected by the role of the device (master/slave).

So far, we had the delayed sniff mode enabled on device A only. For completeness let's check what happens if delayed sniff mode is enabled on device B only. Sniff parameters are kept as usual.

Table 6-12 / Figure 26 show the expected: When entering the connection, device A requests sniff mode immediately (50 ms). After five seconds device B requests sniff mode with its 200 ms. And again, swapping master and slave does not have an impact on the current patterns (see Table 6-13 / Figure 27).

Table 6-12: lpp_table - device B passive mode, 1s, slave

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 40, 50]	[2, 2, 100, 200]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,200	1,200
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 1,0,40,50,2!,2!	[0] 2,1,0,0,0,0 [1] 1,0,100,200,2!,2!
Duration/active	S 364, 365	[0, 0]	[1, 0]

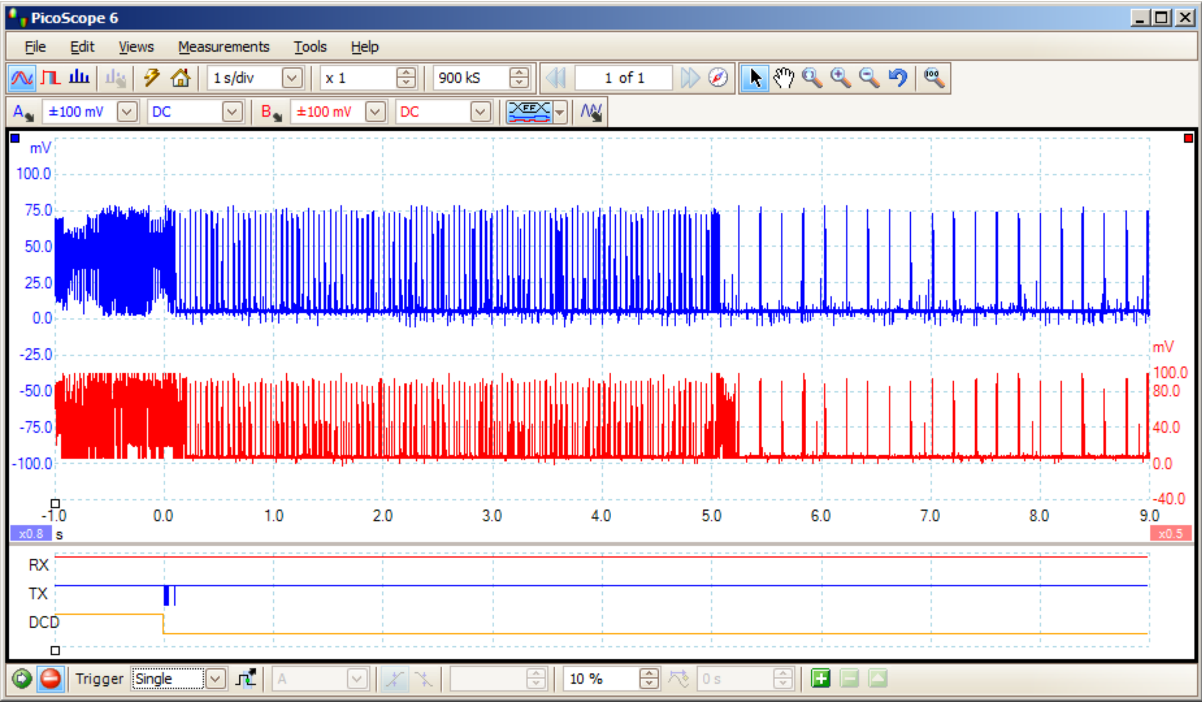

Figure 26: lpp_table - device B passive mode, 1s, slave

Table 6-13: lpp_table - device B passive mode, 1s, master

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 40, 50]	[2, 2, 100, 200]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	S	M
pwr.mode/intv.	ATI144	1,200	1,200
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 1,0,40,50,2!,2!	[0] 2,1,0,0,0,0 [1] 1,0,100,200,2!,2!
Duration/active	S 364, 365	[0, 0]	[1, 0]

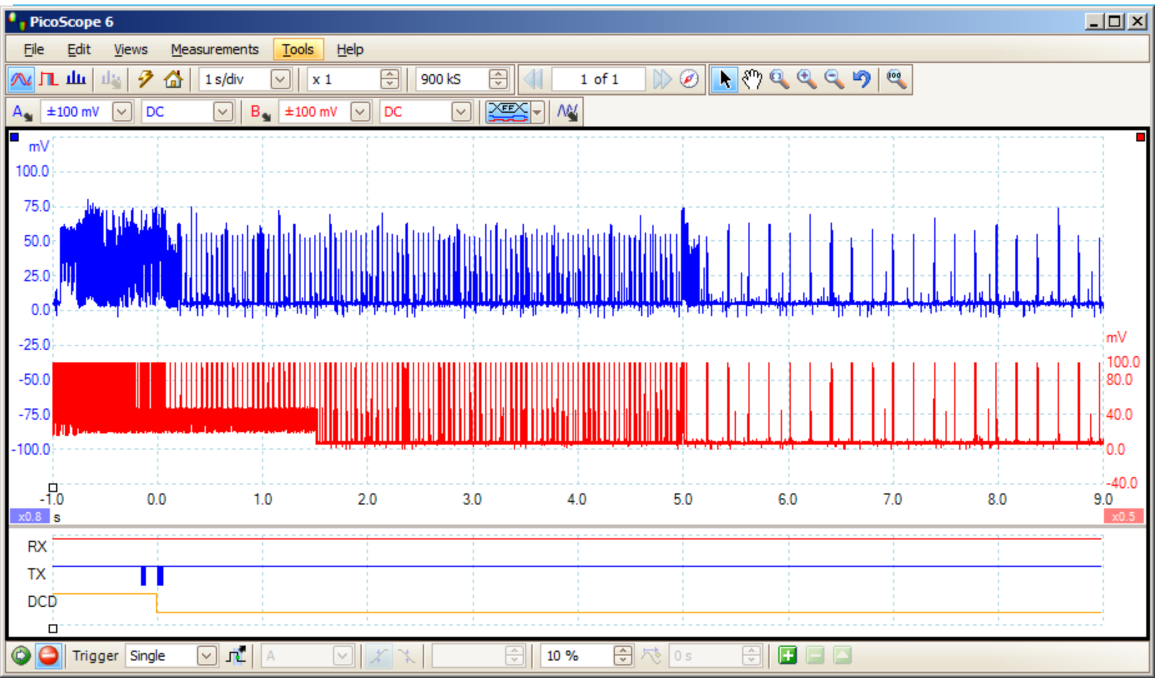

Figure 27: lpp_table - device B passive mode, 1s, master

6.4.5.1.2 8s Example

As mentioned at the beginning of this chapter, the 5 second effect id not observed with a configured duration of e.g. 8 seconds. So we still go through this example, this time for device B with S364=8 (Table 6-14). Sniff parameters are the same as in the previous examples: 50 ms sniff interval for device A and 200 ms sniff interval for device B.

Row [0] of the table in device B is set to mode 2=passive and duration = 8 seconds. Hence it will not initiate a change of power settings for 8 seconds after row [0] is activated (connection established). After this timeout (and no data being exchanged), row [1] is activated. Row [1] is set to mode '1' (sniff, autonomously set by AT-firmware) for indefinite duration (0) with sniff parameters controlled by S561 … S564. Hence, after 8s device B requests sniff mode with its parameters, indicated by Figure 28. The next event on which row [0] will be re-activated is an exchange of data (Figure 29). But as the mode of row [0] is 'passive', no change of power mode will be initiated by device B for eight seconds. After the eight second no-data timeout, device B will again request its sniff parameters. But as device A didn't change any sniff parameters, no change will be seen at that event either.

Table 6-14: lp_table - device B initial duration=8s, passive

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 40, 50]	[2, 2, 100, 200]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,200	1,200
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 1,0,40,50,2!,2!	[0] 2,8,0,0,0,0 [1] 1,0,100,200,2!,2!
Duration/active	S 364, 365	[0, 0]	[8, 0]

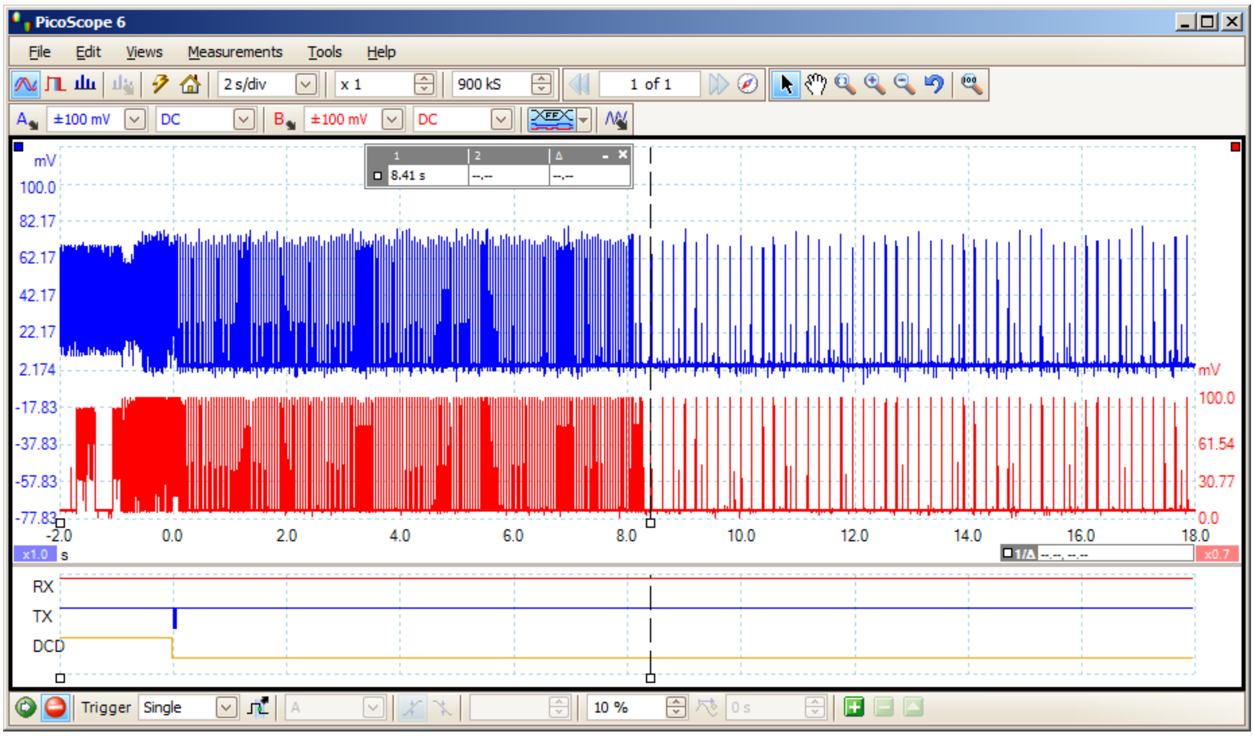

Figure 28: lpp_table - device B initial duration=8s, passive

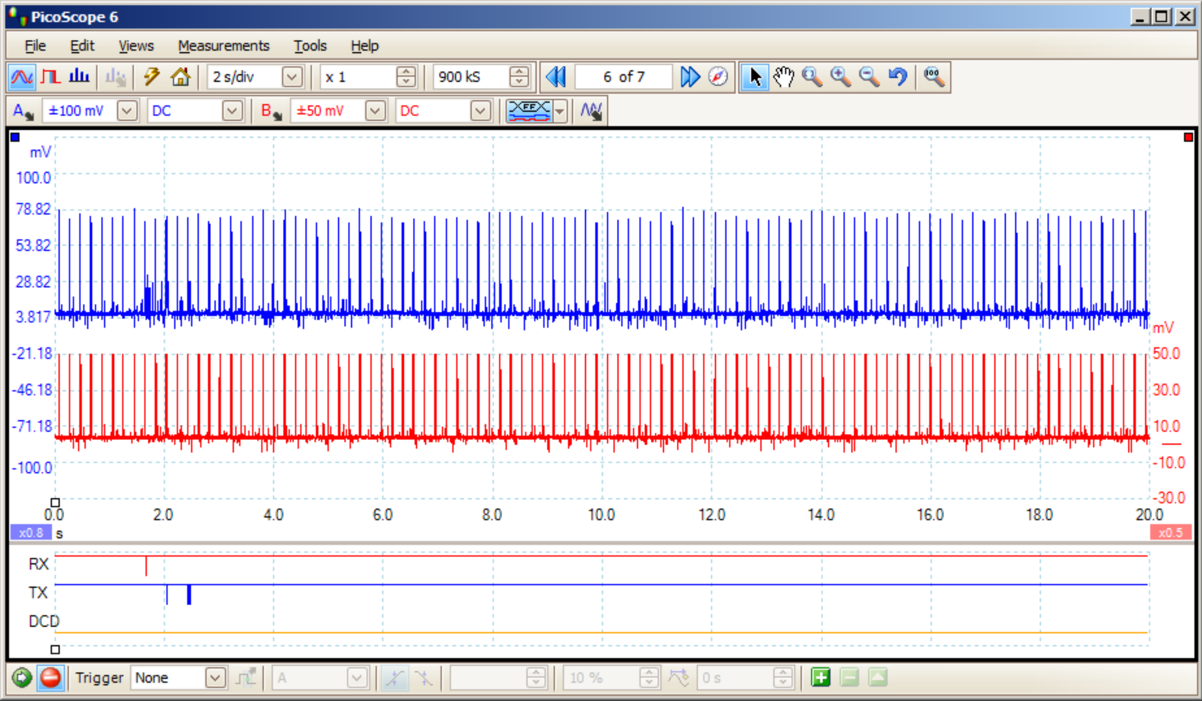

Figure 29: lpp_table - device B duration=8s, passive, with data transmitted

Conclusion: the sniff interval doesn't change any more on data transmission in the configuration described

6.4.5.1.3 Both Ends

For the final example of lpp_table characteristics, we set the duration at two seconds for device A and one second for device B. Both ends have passive mode (2) in row [0] (Table 6-15). This gives priority to the sniff settings of device A because they will apply later than device B and therefore persist on the link. As Figure 30 shows, we have reached the goal, but the timing is not as expected. Sniff mode with device A parameters (50 ms interval) is entered only six seconds after the connection is established. This is probably related to the "five second effect". We can also see the initial active mode for about one second in Figure 30.

Table 6-15: lpp_table, devA=2s, devB=1s

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 40, 50]	[2, 2, 100, 200]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,50	1,50
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lpp_table	ATI146	[0] 2,2,0,0,0,0 [1] 1,0,40,50,2!,2!	[0] 2,1,0,0,0,0 [1] 1,0,100,200,2!,2!
Duration/active	S 364, 365	[2, 0]	[1, 0]

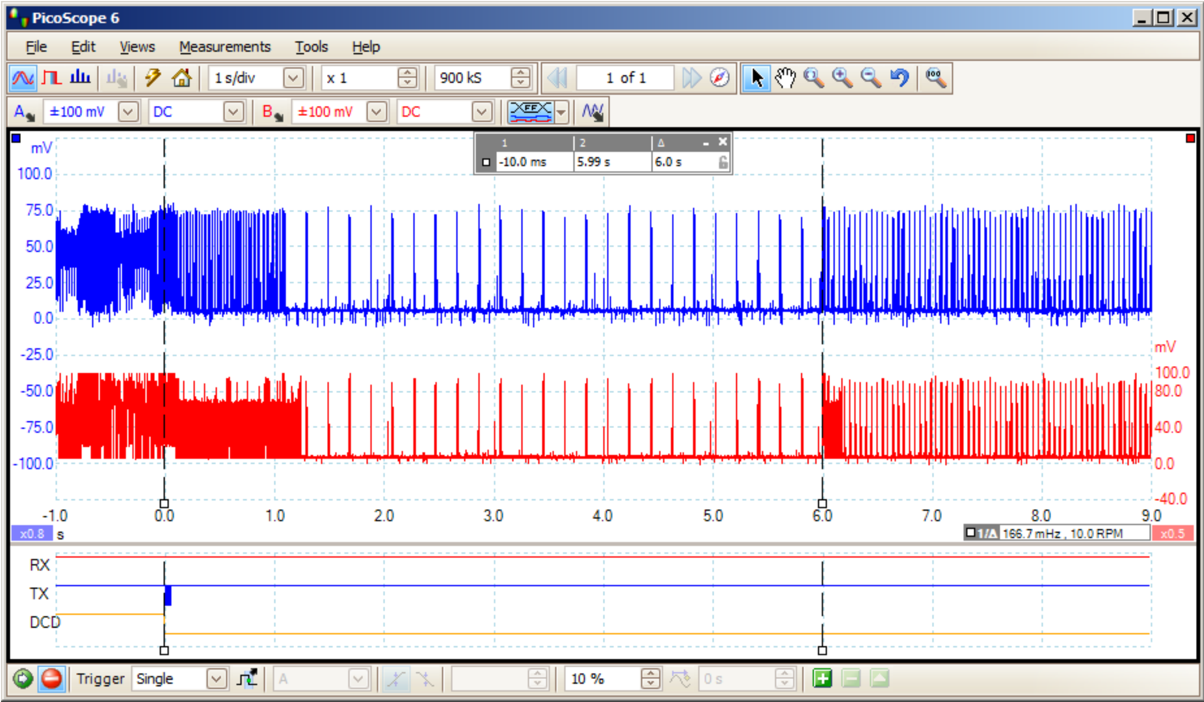

Figure 30: lpp_table, device A=2s, device B=1s

If the durations (S364) are swapped between the devices (Table 6-16), nothing unexpected occurs. Device B's sniff interval (200 ms) remains on the link due to its request occurring later than device A's request (shown in Figure 31).

Table 6-16: lpp_table, device A=1s, device B=2s

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 40, 50]	[2, 2, 100, 200]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,200	1,200
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 2,1,0,0,0,0 [1] 1,0,40,50,2!,2!	[0] 2,2,0,0,0,0 [1] 1,0,100,200,2!,2!
Duration/active	S 364, 365	[1, 0]	[2, 0]

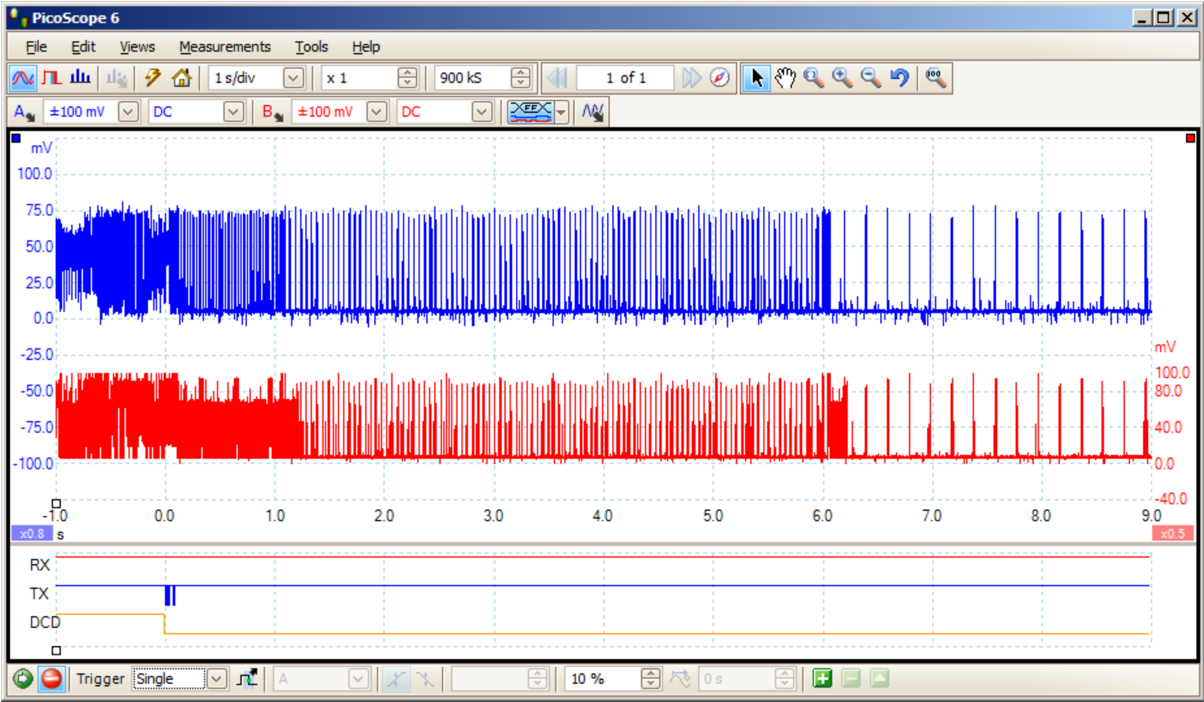

Figure 31: lpp_table, device A=1s, device B=2s

6.4.5.2 Active Mode (S365=1)

The following example demonstrates the use of active mode. With regards to power savings, this may not be particularly useful but is worth mentioning when demonstrating the lpp_table behaviour.

For device B, we again set a duration of one second (S364=1) and enable active mode for row [0] (S365=1). Whenever any data is transmitted, device B requests active mode (row [0]) and, after one second of no data transmitted, it requests its sniff parameters (200 ms, row [1]). The appropriate current patterns are shown in Figure 32.

This could be useful if large amount of data is supposed to be transmitted after a long time of no data transmission. However, it is highly recommended that you use sniff mode with an appropriate timeout parameter to cater for dynamic amounts of data, rather than utilising the lpp_table with active mode.

Table 6-17: lpp_table, device B initial duration=1s, active mode

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 40, 50]	[2, 2, 100, 200]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,200	0,0
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 1,0,40,50,2!,2!	[0] 0,1,0,0,0,0 [1] 1,0,100,200,2!,2!
Duration/active	S 364, 365	[0, 0]	[1, 1]

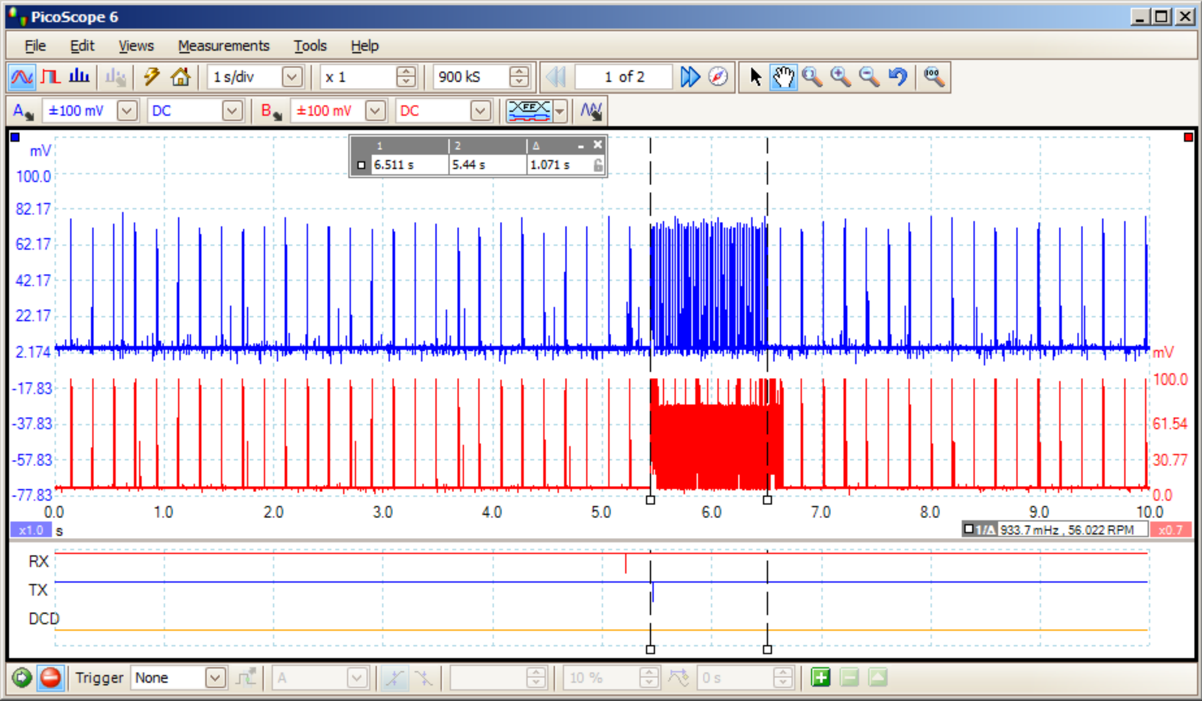

Figure 32: lp_table - Device B initial duration = 1s, active mode

6.4.6 Data Latency in Sniff Mode

This section will demonstrate the impact of various sniff mode parameters on data latency. In the hardware setup which was used to produce the screenshots, the UART of device A (blue) is connected to a terminal program on a PC. RX, TX and DCD are signals of device A's UART. Device B (red) is in remote command mode. When entering a connection, we are connected to the command parser of device B. Any character that is sent by the terminal passes the RX line of device A, is sent over the air to device B. So when sending e.g. "ATI\r" on the terminal, the echo (if enabled) and the command response are received over the air from device B. Finally, the command response passes the TX line of device A and is displayed on the terminal screen.

The first example shows sniff mode with some data. Sniff interval is 100 ms, attempt and timeout have the minimum value of 2 set, see Table 6-18. The serial data "ati\r" is sent to the UART of the local BTM41x (current curve blue, digital "RX" line red) at the first marker (Figure 33). Only at beginning of the next attempt phase (at about 620 ms), this data is transmitted to the remote device over the air. The remote BTM41x's echo is locally received at the second marker, with a total delay of 195 ms. A response is still expected from the remote end: "Laird Bluetooth Data Module 410\r\nOK\r\n". This response is received on device A at 917 ms in Figure 33. The total time for the command to finish is 443 ms.

Table 6-18: data latency, 100 ms sniff interval dev. A, minimum attempt and timeout [2,2,..]

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 90, 100]	[0, 0, 0, 2]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,100	1,100
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 1,0,90,100,2!,2!	[0] 2,0,0,0,0,0
delay echo/resp.		195 ms / 443 ms	

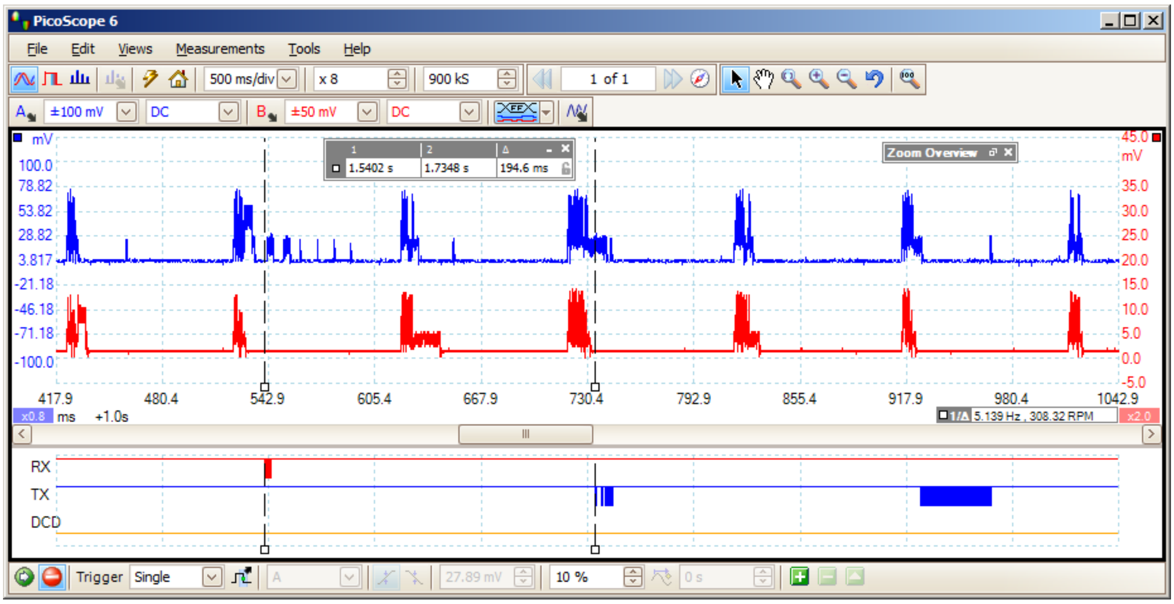

Figure 33 : Data latency, sniff interval = 100 ms, attempt=5 ms

Now let's increase the attempt parameter to spend more time on RF activity. We set ATS561=30 (which in v16.1.3.1 translates to 60 ms, see section 6.2). As shown in Table 6-13 we achieve a much lower delay of 50 ms/160 ms for echo/response. However, when observing the current in Figure 34, we see that this improvement causes significant power consumption. Now the devices spend 60% of the time (60 ms/100 ms) active, regardless of data being exchanged or not (static consumption).

Table 6-19: Data latency, attempt=30 (60 ms)

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[30, 2, 90, 100]	[0, 0, 0, 2]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,100	1,100
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 1,0,90,100,30,2!	[0] 2,0,0,0,0,0
delay echo/resp.		50 ms / 160 ms	

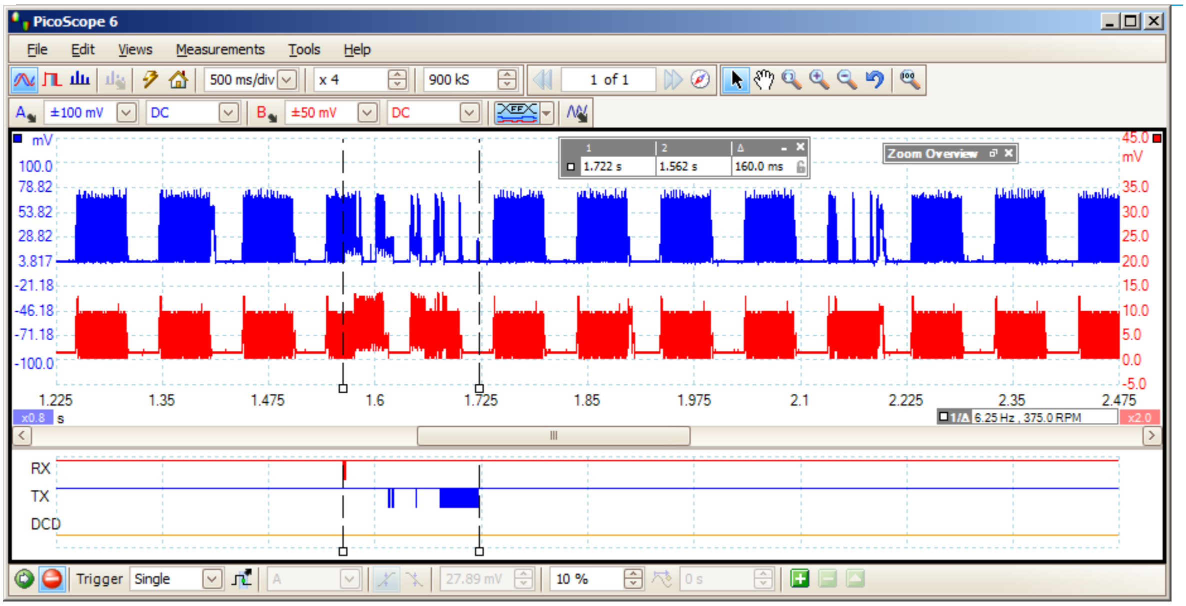

Figure 34: data latency, attempt=60 ms

We now reduce the attempt window to e.g. ATS561=10 (which in v16.1.3.1 translates to 20 ms, see section 6.2). Now with 20% of the time active, we achieve 96 ms for the echo and 239 ms for the response, see Table 6-20 / Figure 35. So it is something in between the previous examples.

Table 6-20: Data latency, attempt=10 (20 ms)

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[10, 2, 90, 100]	[0, 0, 0, 2]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,100	1,100
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 1,0,90,100,10,2!	[0] 2,0,0,0,0,0
delay echo/resp.		96 ms / 239 ms	

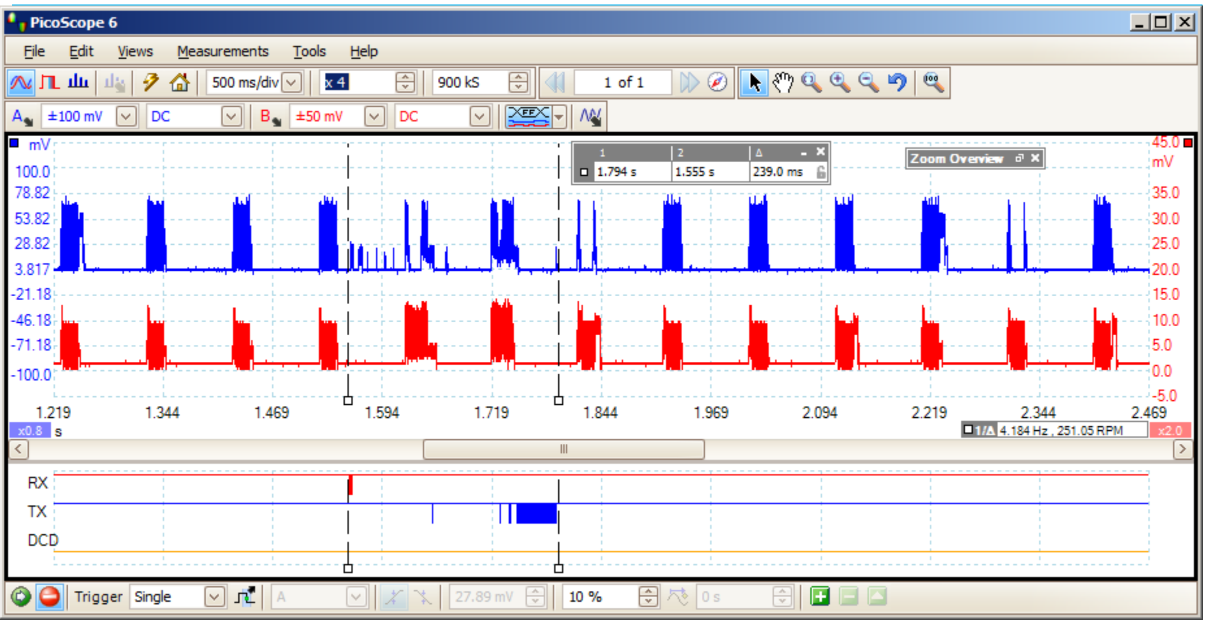

Figure 35: Data latency, attempt=10 (20 ms)

Conclusion: The attempt parameter (S561) allows controlling the trade-off between data delay and current consumption in a linear and static way. This parameter doesn't allow dynamic adjustment to a varying amount and/or timing of data.

So far, we haven't looked at the sniff mode timeout parameter yet (S562). With the previous conclusion regarding the attempt parameter, we want to minimise the static power consumption so we set 'attempt' back to the minimum (ATS561=2). Now we choose a value of ATS562=10 for timeout (which in v16.1.3.1 translates to 20 ms, see section 6.2), and see what happens.

The result is quite exceptional (see Table 6-21 / Figure 36): We achieve a delay of 53 ms for the echo and 144 ms for the response, which is similar to the previous example with attempt=30 (60 ms). Compared to the previous example with 60% static power consumption, now we have a static power consumption of 5% (5 ms/100 ms). I.e. when no data being exchanged, the current peaks are nicely thin. We are quite close to the goal of only spending power when most needed.

Table 6-21: Data latency, timeout=10 (20 ms), attempt=2 (5 ms)

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 10, 90, 100]	[0, 0, 0, 2]
Ssr	S 348, 349, 350	[0, 0, 0]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,100	1,100
ssr param.	ATI145	0,0,0,0,0	0,0,0,0,0
lp_table	ATI146	[0] 1,0,90,100,2!,10	[0] 2,0,0,0,0,0
delay echo/resp.		53 ms / 144 ms	

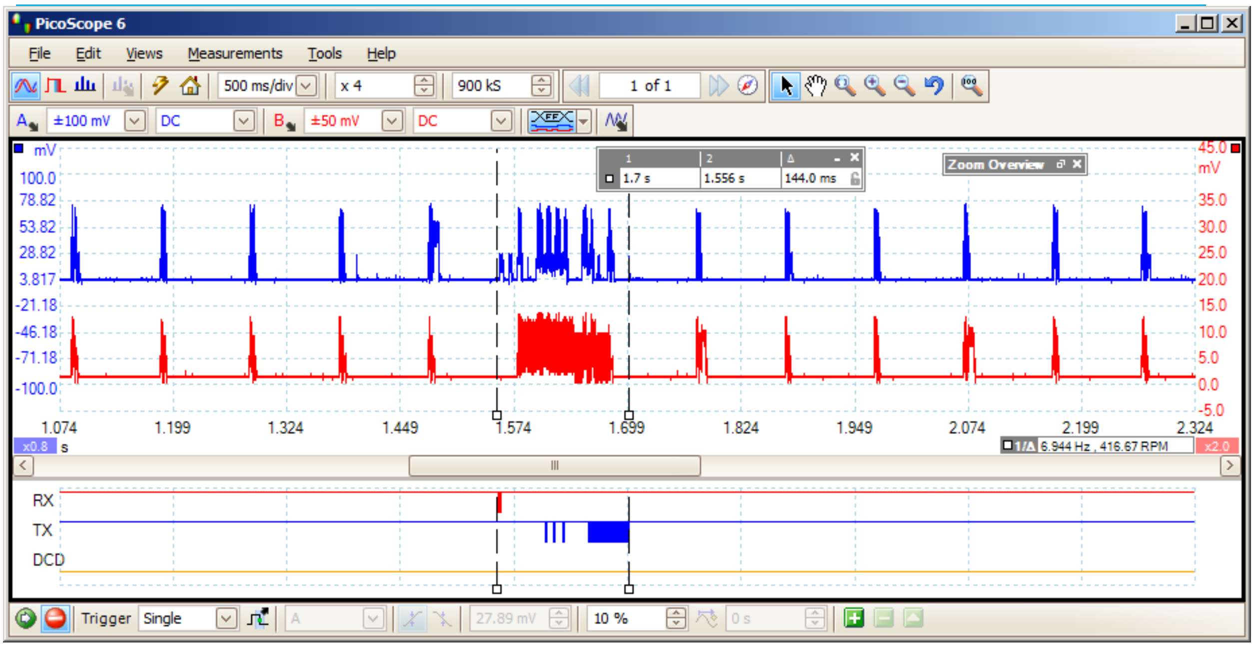

Figure 36: Data latency, timeout=10 (20 ms), attempt=2 (5 ms)

Conclusion: The sniff mode timeout parameter (S652) plays a key role in optimised power settings for dynamic amount of data. This parameter allows spending power only when really needed for data exchange, our main goal at the start of this document.

6.4.7 Sniff Sub-Rating

This section of examples is dedicated to present characteristics of Sniff sub-rating (SSR). As the name says, sniff sub-rating is a sub mode of the sniff mode.

6.4.7.1 Set SSR on Device A

In the first example (see Table 6-22) we set the basic sniff mode parameters on device A: interval=100 (S564), attempt and timeout=2 (S561, S562). Now we allow the remote device (B) to be absent for at maximum 700 ms in sub-rating (S348=7). In addition we allow device B to enter sniff mode after a timeout of at least 1000 ms (S349=10) when no data is exchanged. For the local baseband we define that we have to stay in sniff mode for at least 1000 ms when no data exchanged (S350=10).

On device B, all SSR registers are set to 0. That means that device B doesn't allow device A any greater absence than the current sniff interval (S348=0). S349=0 means that device A is allowed to change to sub-rating immediately when no data transmitted. But, as an extended sub-rating interval is not permitted (S348=0), S349 doesn't have any effect here. And finally, device B allows itself entering sub-rating immediately when no data transmitted (S350=0).

The resulting current patterns are shown in Figure 37.

Table 6-22: sub-rating, only device B allowed

		DevA (blue)	DevB (red)

Sniff	S 561, 562, 563, 564	[2, 2, 90, 100]	[0, 0, 0, 2]
Ssr	S 348, 349, 350	[7, 10, 10]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,100	1,100
ssr param.	ATI145	1,100,700,1000,1000	1,700,100,1000,0
lp_table	ATI146	[0] 1,0,90,100,2!,2!	[0] 2,0,0,0,0,0

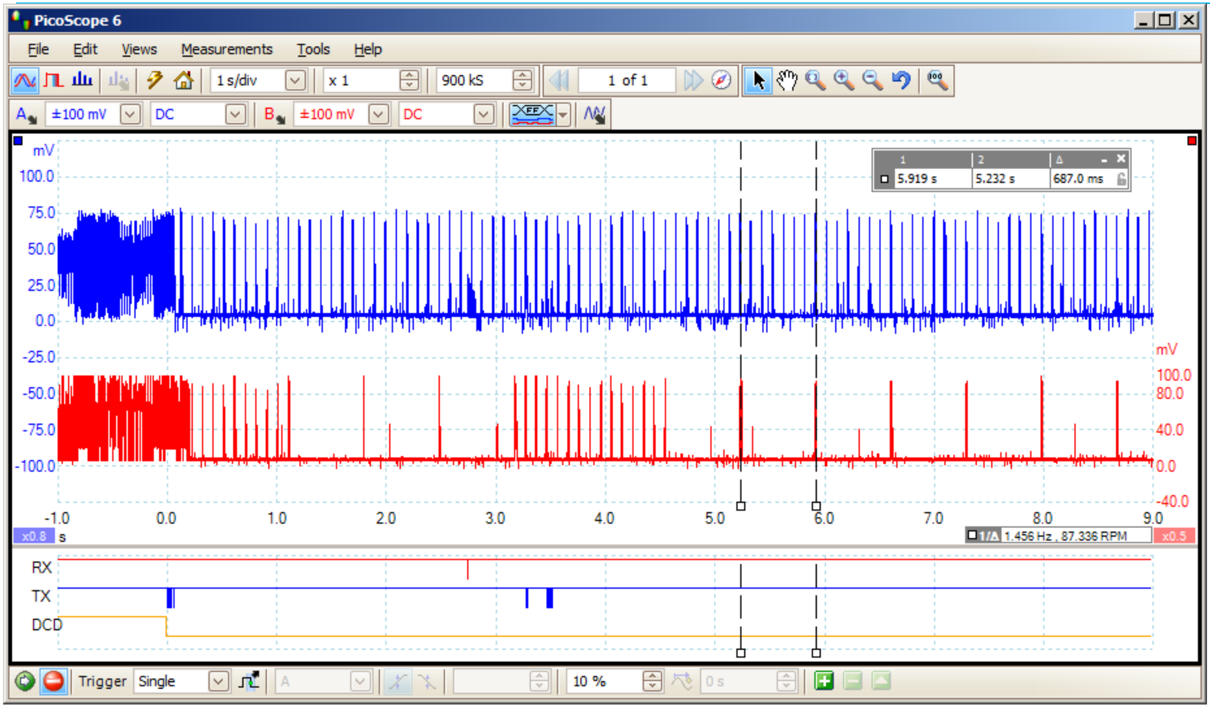

Figure 37: sub-rating, only device B allowed

On establishing a connection, both devices enter sniff mode. It can be observed that device A is remaining in the 100 ms sniff interval all time. As there is no data transmitted, after a one second timeout device B changes to sub-rating with the new interval of 700 ms.

The one second timeout is the result of comparing devA-S349=10 and devB-S350=0 and applying the greater value (minimum remote timeout devA = 10 vs. minimum local timeout devB = 0).

The 700 ms interval is selected by the baseband because it is a whole numbered multiple of the 100 ms sniff interval.

The next event is the data traffic at 2.75 seconds. Device B reverts to sniff mode. Data exchange occurs with the sniff rate of 100 ms rather than at the 700 ms sub-rating interval.

With the 1 s timeout after the last data transmitted, device B transitions back to sub-rating at 4.5 seconds.

Conclusion: The switching back and forth between sniff interval and sub-rating interval is a typical characteristic of sniff sub-rating. Compared to basic sniff mode, the change to a sub interval and back doesn't have to pass through active mode, which is saving some power. In addition, sub-rating can be asymmetric. Whereas in sniff mode both ends always have the same sniff interval, the extended absence in sub-rating doesn't have to be identical for both ends, as demonstrated in this first example.

6.4.7.2 Reducing Timeout

In the next step, let's reduce the timeout to go back to sniff mode earlier after a data transmission. With S348=5 on device A we'll set it to 500 ms. As still S349=0 on device B, the 500 ms should apply (Table 6-23). No surprise in Figure 38: device B changes to sub-rating 500 ms earlier than in the preceding example. This can be observed twice: first after link establishment and a second time after the data events. By the way, current sub-rating parameters can be queried by ATI145 or ATI45.

Table 6-23: sub-rating, timeout=500 ms

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 90, 100]	[0, 0, 0, 2]
Ssr	S 348, 349, 350	[7, 5, 10]	[0, 0, 0]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,100	1,100
ssr param.	ATI145	1,100,700,1000,500	1,700,100,500,0
lp_table	ATI146	[0] 1,0,90,100,2!,2!	[0] 2,0,0,0,0,0

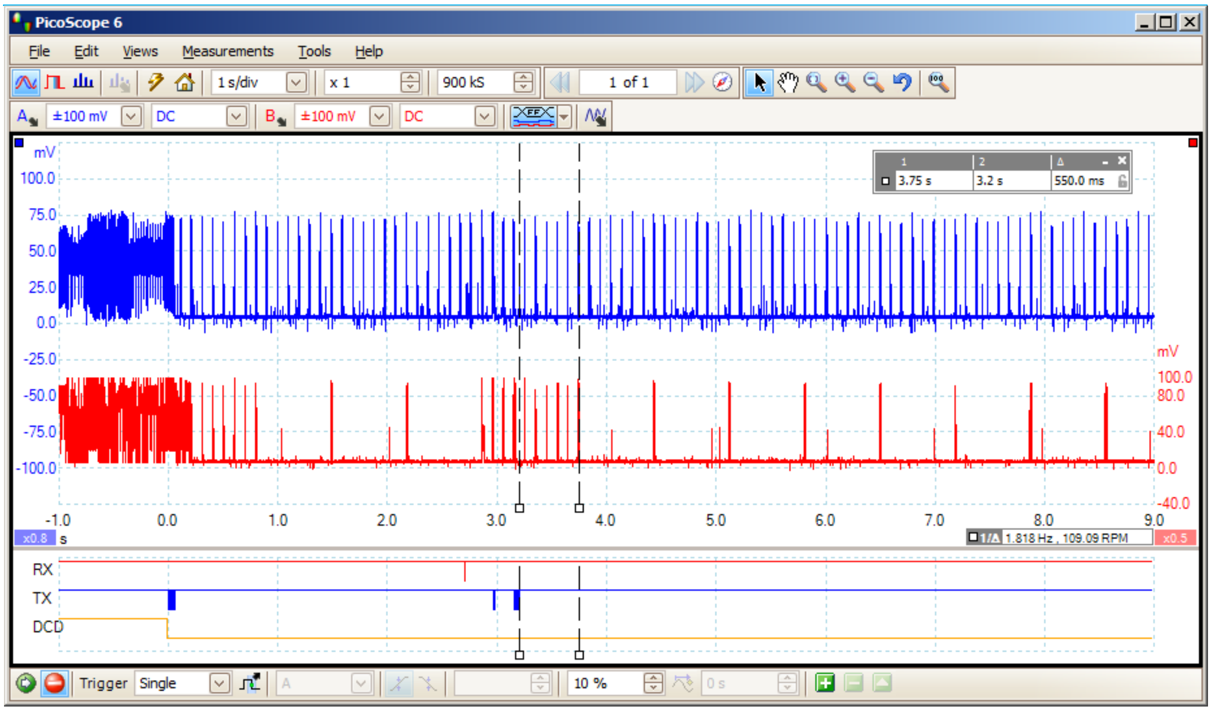

Figure 38: sub-rating, timeout=500 ms

6.4.7.3 Set SSR on Device B

Now let's set some SSR parameters on device B. By setting ATS348=3, we allow device A an extended absence to a maximum of 300 ms in sub-rating. With S349=10 on device B, we set a one second timeout for device A. Comparing to S350 on device A, which is 10 as well, one second will result as the timeout for device A before entering sub-rating. With ATS350=10 on device B we override the 500 ms set by S349 on device A. The resulting timeout will be one second now for device B before entering sub-rating. This may or may not be meaningful, but is presentedhere for demonstration.

Table 6-24: SSR registers set on device B

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 90, 100]	[0, 0, 0, 2]
Ssr	S 348, 349, 350	[7, 5, 10]	[3, 10, 10]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,100	1,100
ssr param.	ATI145	1,300,600,1000,500	1,600,300,1000,1000
lp_table	ATI146	[0] 1,0,90,100,2!,2!	[0] 2,0,0,0,0,0

Now we can make an interesting observation in Table 6-24 (ATI145) and Figure 39: The new sub-rating interval for device A is 300 ms, as permitted by device B, fair enough. But the sub-rating interval for device B is not 700 ms anymore, but now 600 ms. How does this happen? The reason becomes obvious in the current pattern (Figure 39): if the sub-rating interval remains 700 ms, both devices won't be active at the same time and cannot maintain the link when sub-rating. With 300 ms / 600 ms, device A meets device B at every 2nd sub-rating interval. With these intervals, the maximum extended absences of both ends (S348, 300 ms/700 ms) are still within limits.

Conclusion: The basebands of both ends arrange a sub-rating interval that meets the requirements of both ends. The actual sub-rating interval can be less than specified by S348. This is why this parameter is called "maximum remote latency".

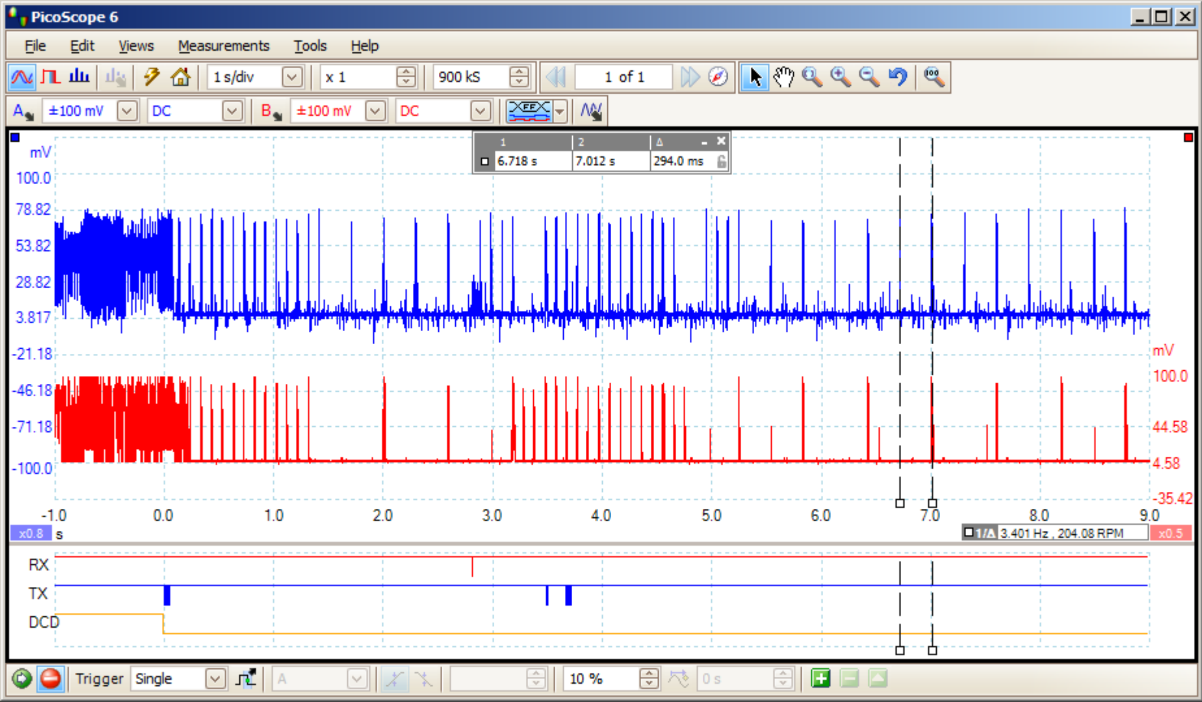

Figure 39: SSR registers set on device B

Sending ATI later + zoomed:

Figure 40 below shows the same configuration (300 ms / 600 ms) zoomed and with some data events.

Figure 40: SSR registers on device B, zoom

6.4.7.4 Set SSR on Device B, Now Local Timeout=5:

It was already mentioned (and can be observed in Figure 39 and Figure 40) that S350=10 on device B overrides ATS349=5 on device A with a resulting timeout of 1000 ms. As a consequence, device B enters sub-rating only after 1 second.

The last example for sub-rating is going to demonstrate a local timeout of 500 ms (ATS350=5) on device B as well (see Table 6-25). The result in Figure 41 confirms the timeout of 500 ms for device B: First after link establishment and again after the data events (RX/TX).

Table 6-25: sub-rating, local timeout=500 ms on dev B

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 2, 90, 100]	[0, 0, 0, 2]
Ssr	S 348, 349, 350	[7, 5, 10]	[3, 10, 5]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,100	1,100
ssr param.	ATI145	1,300,600,1000,500	1,600,300,500,1000
lp_table	ATI146	[0] 1,0,90,100,2!,2!	[0] 2,0,0,0,0,0

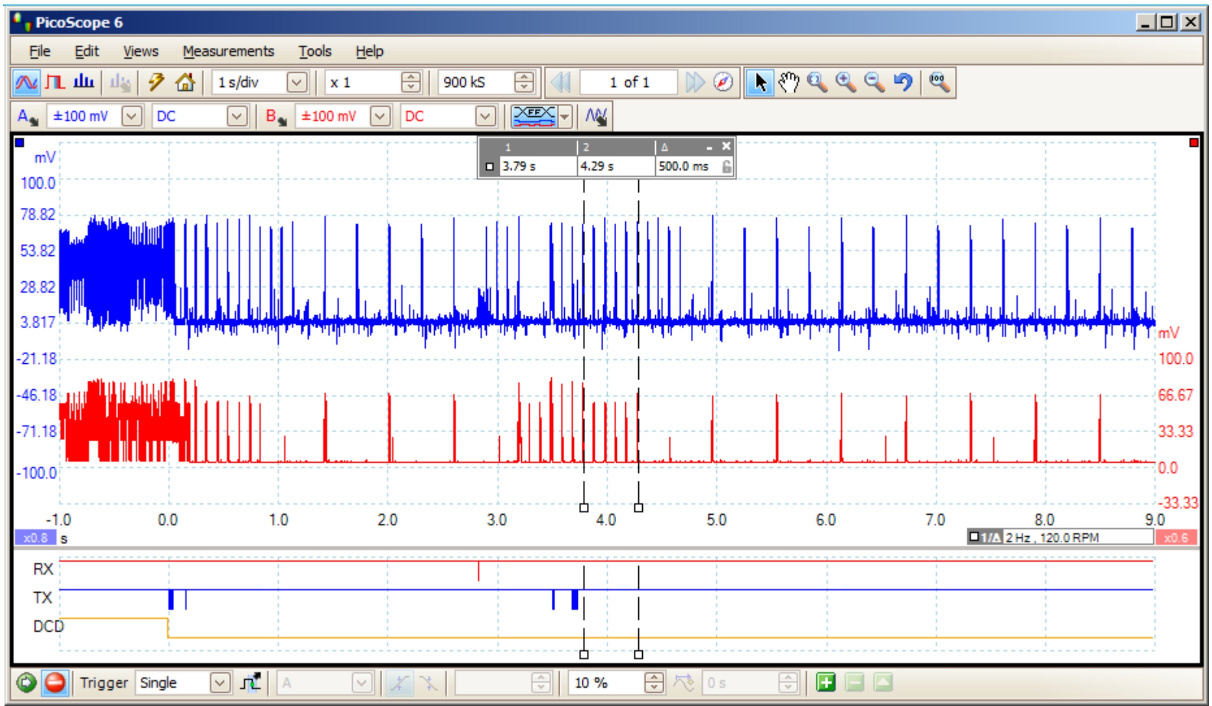

Figure 41: sub-rating, local timeout=500 ms on dev B

6.4.8 The Optimal Setting for a Real World Example

Finally, we want to apply the knowledge about sniff mode and sub-rating in order to find the optimal setting for power consumption and latency. It should also be clear now that the optimal setting depends significantly on the expected timing and amount of data.

So let's say, in our application we transmit a block of 50 bytes about every 2 seconds. The maximum acceptable delay should be 500 ms. We also want to allow sub-rating for times of no data transmission. The sub-rating interval will present the greatest latency, so let's allow at max. 400 ms (S348=4). For the sniff interval we choose 100 ms (S564=100), as this is ¼ of 400 ms. In order to make sure that this sniff interval applies to the link, we set these sniff parameters (S561…S564) at one end (device A) only, and we disable sniff mode on device B. We want to enter sub-rating quickly, so for the local and remote timeouts we choose quite a low value of 200 ms (S349=2, S350=2). Finally, the timeout parameter (S562) is quite sensible, we choose 40 ms here (S562=20) to make sure that available data doesn't have to wait until beginning of the next sniff interval. For the attempt parameter we choose a low value of 5 ms (S561=2), keeping the periodic current peaks thin.

Device B doesn't echo the block of 50 bytes this time (ATE0). It just responds with "ERROR05" as the 50 byte block (plus '\r') is not a meaningful AT command.

The response delay measured varies between 250 ms and 450 ms (see Table 6-26). So the requirement of the maximum acceptable delay (500 ms) is met. We also reach the goal of consuming power only when most needed, as shown in Figure 42.

Table 6-26: real world example, optimised settings

		DevA (blue)	DevB (red)
Sniff	S 561, 562, 563, 564	[2, 20, 90, 100]	[0, 0, 0, 2]
Ssr	S 348, 349, 350	[4, 2, 2]	[4, 2, 2]
Ma/Sl	ATI43	M	S
pwr.mode/intv.	ATI144	1,100	1,100
ssr param.	ATI145	1,400,400,200,200	1,400,400,200,200
lp_table	ATI146	[0] 1,0,90,100,2!,20	[0] 2,0,0,0,0,0
response delay	[260; 450; 260; 440; 250] ms		

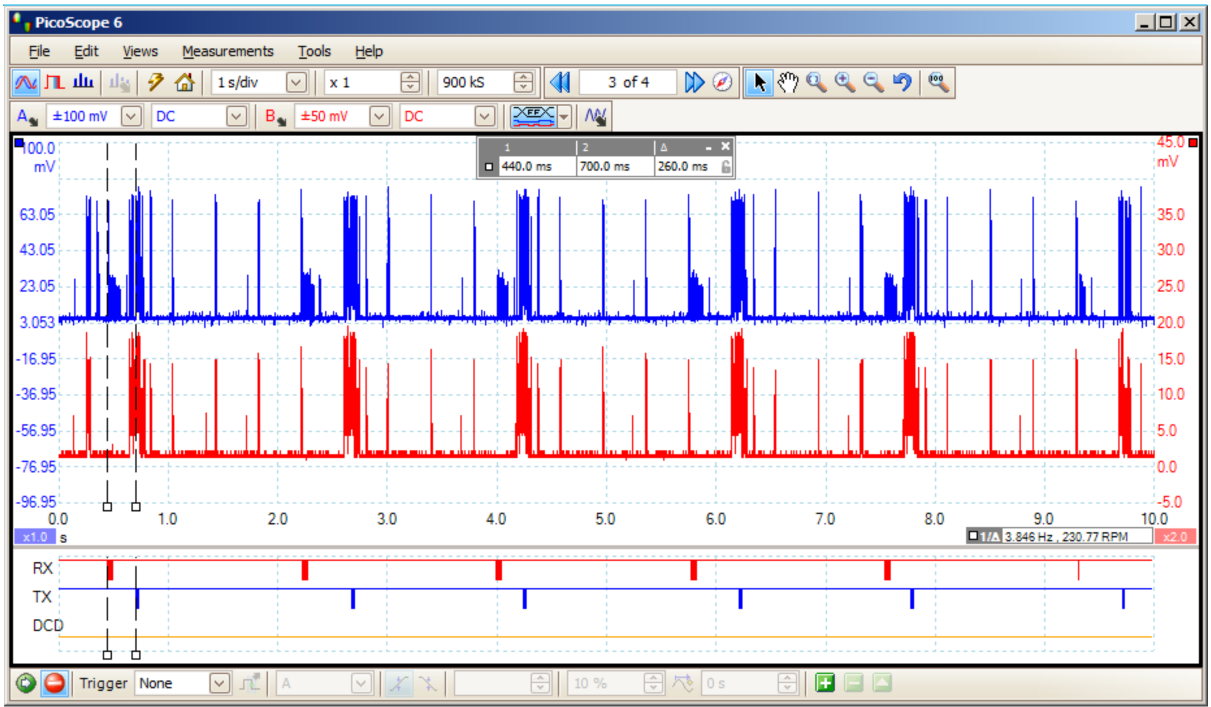

Figure 42: real world example, optimised settings

7 Revision History

Revision	Date	Description	Approved By
1.0	26 June 2013	Initial Release	Jonathan Kaye
1.1	03 Mar 2015	Added Revision History	Sue White