A METHOD FOR SYNCHRONISING TRANSMITTER AND RECEIVER ANTENNA SWITCHING WHEN PERFORMING DUAL ARRAY MEASUREMENTS

Per H. Lehne(1), Magne Pettersen(2), Ragnar Eckhoff(3), Odd Trandem(4)

(1) Telenor Research and Development, N-1331 Fornebu, Norway, E-mail: per-hjalmar.lehne@telenor.com

(2) As (1) above, but E-mail: magne.pettersen@telenor.com

(3) As (1) above, but E-mail: ragnar.eckhoff@telenor.com

(4) SINTEF Telecom and Informatics, N-7465 Trondheim, Norway, E-mail: odd.trandem@informatics.sintef.no

ABSTRACT

Doing multi sensor measurements usually employs switching between a number of antenna elements in order to record a spatial channel response. When employing arrays at both ends, i.e. both transmitter and receiver, in order to estimate the double directional channel, a synchronising problem arises. This paper describes a practical solution to this problem using different methods dependent on which possibilities are feasible in the chosen measurement scenarios. The setup is part of a new chirp based channel sounder capable of doing double directional channel measurements. It uses both GPS (Global Position System), transmitter-receiver (Tx-Rx) interconnection and Rubidium (Rb) frequency standards in different combinations.

INTRODUCTION – CHANNEL SOUNDER OVERVIEW

In order to make fast multi sensor measurements, fast and accurate switching is essential. Having an array at the receiver end only of the link is straight forward because no involvement of the transmitter is necessary. When arrays are introduced at both ends, the switching will have to be synchronised.

In an indoor and short range scenario, transmitter and receiver can be interconnected using a cable, however when the measurement range increases, this is no longer feasible. By equipping the sounder with high quality frequency references combined with Global Position System (GPS) time reference receivers, a sufficient synchronism can be achieved over the required measurement period. The new setup also employs the possibility of connecting the two ends by IP in order to exchange time stamp information, so remote synchronisation can be done. The switching scheme also takes into account the practical consequences of the radio delay between transmitter and receiver when setting up the timing schedule.

A new channel sounder has been developed and built by SINTEF Telecom and Informatics in Trondheim, Norway. The sounder is designed for measuring double-directional channels by the use of fast switching both at transmitter and receiver. The measurement signal used is a linear frequency chirp. The sounder can perform different combinations of measurements, e.g. double-directional impulse response measurements and combined direction of arrival (DoA)/Doppler measurements. The maximum measurement bandwidth is currently 250 MHz, however an extension up to 500 MHz is possible. The RF front ends are exchangeable, so any frequency band is possible. Currently front ends for 2.1 GHz and 100 MHz bandwidth exist.

SYNCHRONISING AND SWITCHING ARCHITECTURE

The synchronising and switching architecture consists of a trigger card, a GPS assisted time reference and an RF oscillator as shown in Fig. 1. The trigger card is designed as a PCI-card which is controlled by an embedded Personal Computer (PC). This is identical at both transmitter and receiver. The PCs can be interconnected through a Local Area Network (LAN).

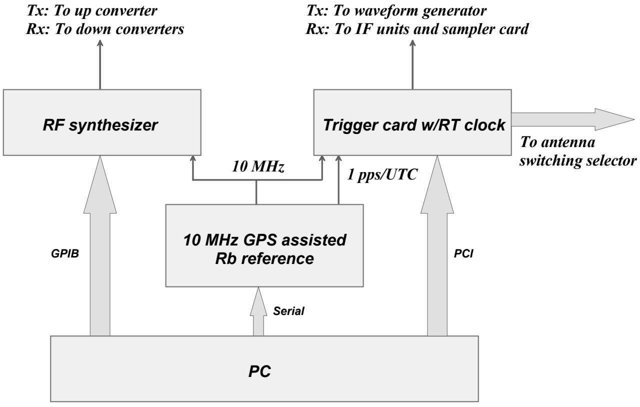

Fig. 1. Block diagram of the timing and frequency circuits.

Measurement modes

The basic measurement modes of the sounder are:

1. Time mode
2. Direction of Arrival mode (DOA)
3. Direction of Departure mode (DOD)
4. Multiple input – Multiple output mode (MIMO)
5. Delay Doppler mode
6. Delay Doppler and Direction of Arrival Mode

In this paper, only the MIMO mode and how to synchronise the Tx and Rx will be described. Fig. 2. below shows how the antenna switching is organised with an example of 4 transmitter and 8 receiver antennas. The receiver sweeps over all its antenna elements between each time the transmitter changes antenna. When all combinations are done, a full MIMO response has been recorded. It is essential to perform this cycle as fast as possible.

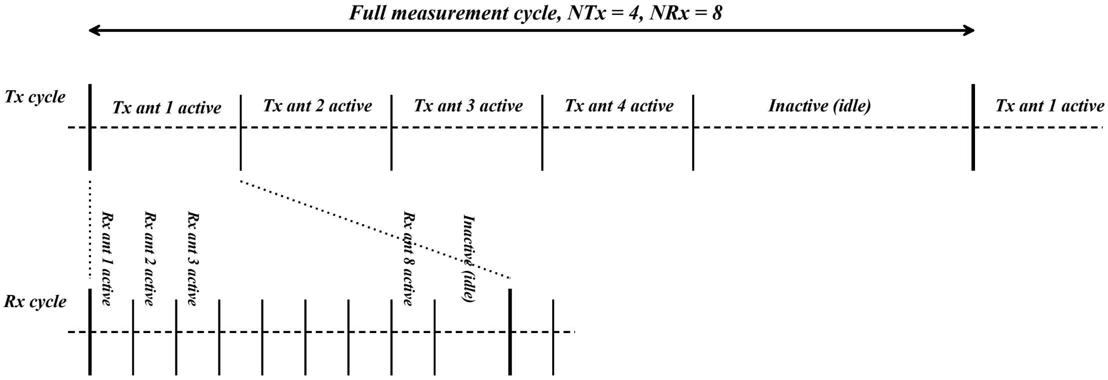

Fig. 2. Antenna switching timing diagram (simplified).

Trigger card

The trigger card's functions are to provide both antenna selector signals as well as start/stop of the measurement cycle. The antenna switching must be synchronised to the channel sounder chirp period. It is the trigger card which performs and controls all the essential functions of the measurement procedures. These are:

- To provide master sampling signals to the receiver sampler card
- To provide measurement trigger pulses, i.e. when the measurement cycles are to start and stop

- To provide gain control signals to the receiver IF circuits
- To provide antenna selector signal

The "heart" of the trigger card is a real time (RT) clock which must be set in order to obtain proper switching synchronisation between transmitter and receiver.

The system is capable of controlling from 2 to 256 antennas at each end, however most practical setups will be confined to maximum 8 antenna elements on each side.

Synchronising transmitter and receiver

The equipment is designed to obtain a RT clock difference between the transmitter and receiver of less than 1 μs. This is accomplished by using two Rb frequency standards as combined time and frequency references. The Rb standards are GPS assisted which provides an absolute UTC (Universal Time Coordinated) time reference with a 1 pps output which is used as the master clock for the trigger card. It also delivers a 10 MHz frequency reference used to lock the system oscillators. After being locked to the GPS time reference, the Rb standards can be run standalone for a fairly long period, usually more than 24 hours. In this case a separate GPS navigation receiver can be used to provide the UTC time reference. It is also possible to use the internal PC clocks in the Tx and Rx as time references, however this requires that the PC clocks have been adjusted in advance by the two afore mentioned UTC time references. Fig. 3 seeks to illustrate these choices. Real time clocks on both Tx and Rx enables the switching cycles to be very near true synchronised, which is required in the case of switching on the transmitter side.

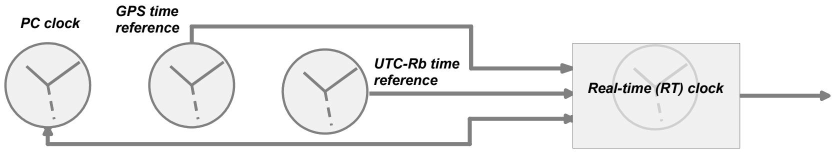

Fig. 3. Different time reference sources can be used dependent on availability.

The equipment can be operated in two main modes. Either the Tx and Rx are connected over a LAN, or Tx and Rx are running standalone. The functions to be performed to prepare the equipment are:

1. The RT clocks in both transmitter and receiver must be set
2. The measurement campaign must be set up so that antenna switching starts at the correct times at both transmitter and receiver

Table 1 below lists the different synchronisation methods which are available in the different operating modes.

Table 1. Synchronisation modes and procedures.

MODE	PROCEDURE	COMMENTS
Network required - Tx and Rx can exchange time reference information over TCP/IP	Synchronise directly over network, master-slave setup. The choice of which entity (Tx or Rx) is master or slave is free.	One of Tx or Rx is used a master time reference without the need for absolute time knowledge (UTC)
	First synchronise RT clock using GPS time reference, then as previous	One of the GPS clocks (Tx or Rx) is used a master time reference.
	First synchronise RT clocks from the Rb-UTC time reference, then as previous	One of the Rb-UTC clocks (Tx or Rx) is used a master time reference.
Standalone - Tx and Rx must establish a common time reference from UTC using its own resources	Adjust RT clock using GPS time reference	Must be performed at both ends (Tx and Rx)
	Adjust RT clock using Rb-UTC time reference	
	Adjust RT clock using PC-clock	Can be used if PC clock has previously been set using GPS or Rb-UTC, and none of these are currently available.
Both modes	No synchronisation	Can be used when synchronisation already have been performed from one of the above methods.

PERFORMANCE MEASURES

The setup has partly been tested in the laboratory and the time needed to do a full multi antenna acquisition is determined by three parts:

1. The time needed to sample the full chirp or chirps
2. Minimum one extra chirp lost in the switching moment
3. An added inactivity period (guard time) for each sub-cycle at the receiver

The full cycle will be substantially longer, but this has nothing to do with the synchronisation itself, but is given by the time needed by the system to process and save the data. The lower limit (theoretically achievable) of the acquisition time is given by

$$t_{\min} = t_{IR} \cdot (N_{av} + 1) \cdot N_{Tx} \cdot N_{Rx} \ , \tag{1}$$

where t_{IR} is the impulse response duration, N_{av} is the number of IRs sampled for per antenna element, N_{Tx} is the number of transmitter antennas and N_{Rx} the number of receiver antennas. There are three timing parameters of the channel sounder which determines the amount of overhead: 1) $T_{Uncertain}$, the timing uncertainty between the Tx and Rx, 2) T_{Swtch}, the estimated settling time for the antenna switches, and 3) $T_{MaxChDly}$, the maximum expected propagation delay from Tx to Rx. Table 2 gives some typical values for acquisition times compared with the lower limit when $T_{Uncertain}$ = 1 µs, T_{Swtch} = 3 µs and $T_{MaxChDly}$ = 1 µs.

Table 2. Typical aquisition times with N_{av} = 1.

Bandwidth [MHz]	**Samples / IR**	**IR length, t_{IR} [µs]**	**$N_{Tx} = 1, N_{Rx} = 8$ Acquisition time [µs]**			**$N_{Tx} = 4, N_{Rx} = 8$ Acquisition time [µs]**			**$N_{Tx} = 8, N_{Rx} = 8$ Acquisition time [µs]**		
			Limit	**Achieved**	**Overhead [%]**	**Limit**	**Achieved**	**Overhead [%]**	**Limit**	**Achieved**	**Overhead [%]**
20	256	12.80	205	205	0.0	819	922	12.6	1638	1843	12.5
	1024	51.20	819	819	0.0	3277	3686	12.5	6554	7373	12.5
100	256	2.56	41	61	48.8	164	276	68.3	328	553	68.6
	1024	10.24	164	164	0.0	655	737	12.5	1312	1475	12.4

The table shows two things: Firstly, the acquisition times increase when switching on both ends are applied. It increases more than just the multiplication of antenna switching should indicate. This is due to the added guard time for each receiver sub-cycle stemming from the timing uncertainty between Tx and Rx and the Tx – Rx propagation delay. Secondly, we can also notice that with extremely short IRs (100 MHz bandwidth and 256 samples/IR), the icrease is much higher. We can also notice that in the case of only 1 Tx antenna, no loss is observed with the exception of the case with the extremely short IR, because no switching is performed at the Tx, and thus no extra guard for Tx – Rx synchronisation is needed.

CONCLUSIONS

An ensemble of methods for synchronising a channel sounder Tx and Rx using dual switching to perform double directional measurements (MIMO) has been presented. Common for the methods is the use of highly accurate frequency and time reference sources. By having several time reference sources, the equipment can be operated under different conditions with or without a network interconnection and still maintain a high degree of stability which gives very short cycle times for a full MIMO cycle. Lab tests have shown that the acquisition time for an 8x8 MIMO measurement in a 20 MHz bandwidth with an impulse response length of 12.8 µs can be done in less than 1.9 ms which is not more than 12.5 % more than the possibly achievable time.