RTCA Special Committee 209 and EUROCAE WG-49

ATCRBS / Mode S Transponder MOPS Maintenance

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REPORT ON
BDS SWAP MEASUREMENTS

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SUMMARY

Working Paper SC209-WP12-23

REPORT ON
BDS SWAP MEASUREMENTS

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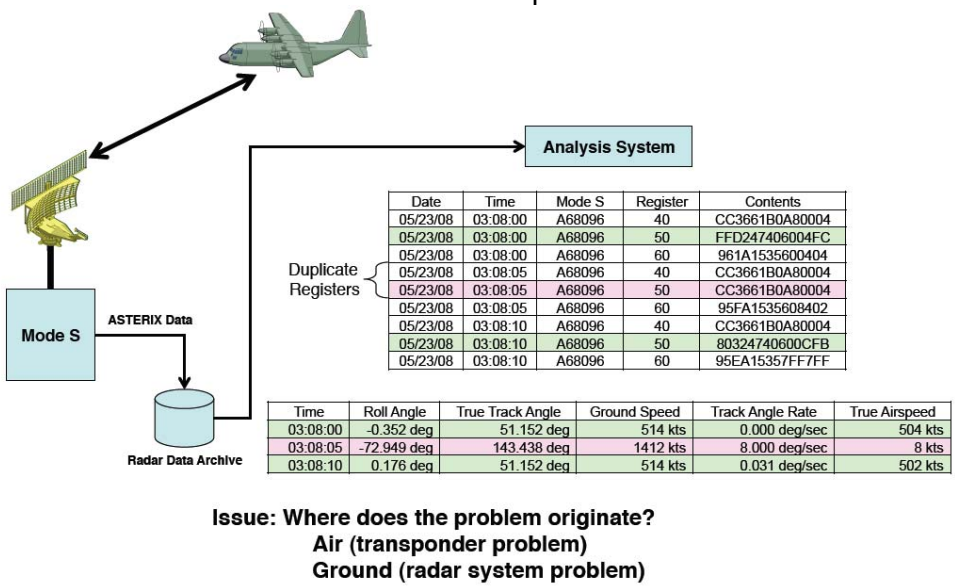
1) Problem definition

Analysis of the daily BDS register data of Mode-S transponders extracted by radars ground station reveals a down-linked BDS register contains an exact copy of a register of different type.

The MIT Lincoln Laboratory working for USAF develops method to verify the USAF aircraft compliance with the European Mode S mandate. Related to the validation of EHS, MIT requested to AMP serials of data on EHS to validate their system. It is working on these data that they discovered the duplication of registers after named BDS swap and they reported this problem in September 2009 to AMP.

In October, LVNL and Maastricht reported the same problem. BELGOCONTROL put in place an adapted verification means and since this period reported systematically the problem to AMP with an occurrence of about 50 cases per day. In November 2009, FAA reported also cases of swap problem in US detected on their Mode S experimental station.



Date	Time	Mode S	Register	Contents
05/23/08	03:08:00	A68096	40	CC3661B0A80004
05/23/08	03:08:00	A68096	50	FFD247406004FC
05/23/08	03:08:00	A68096	60	961A1535600404
05/23/08	03:08:05	A68096	40	CC3661B0A80004
05/23/08	03:08:05	A68096	50	CC3661B0A80004
05/23/08	03:08:05	A68096	60	95FA1535608402
05/23/08	03:08:10	A68096	40	CC3661B0A80004
05/23/08	03:08:10	A68096	50	80324740600CFB
05/23/08	03:08:10	A68096	60	95EA15357FF7FF

Time	Roll Angle	True Track Angle	Ground Speed	Track Angle Rate	True Airspeed
03:08:00	-0.352 deg	51.152 deg	514 kts	0.000 deg/sec	504 kts
03:08:05	-72.949 deg	143.438 deg	1412 kts	8.000 deg/sec	8 kts
03:08:10	0.176 deg	51.152 deg	514 kts	0.031 deg/sec	502 kts

Figure 1 MIT picture showing the duplicated registers

The example below shows the problem meet with aircraft “AE04CF” which is a BOEING KC-135R military aircraft. In this case, the problem appears every one or two minutes.

sac	sic	time	ModeS	ACID	typ	reg	BDS40	BDS50	BDS60
6	5	10:52:53.56	AE04CF	RCH205	K35R	62-3537	FF7D033CBFFCF6	FF7D033CBFFCF6	E62A05346007FF
6	5	10:55:15.30	AE04CF	RCH205	K35R	62-3537	FFBCFF3C7FFCF9	FFBCFF3C7FFCF9	E66A0934E01401
6	3	10:55:58.43	AE04CF	RCH205	K35R	62-3537	FF9CFF3C7FFCF8	FF9CFF3C7FFCF8	E66A0734A007FF
6	3	10:56:57.58	AE04CF	RCH205	K35R	62-3537	887D053BE07CF9	887D053BE07CF9	E69A0934A007FF
6	5	10:58:00.46	AE04CF	RCH205	K35R	62-3537	FF9D8D3CBFFCF7	FF9D8D3CBFFCF7	EAFA0534600400
6	3	10:59:19.34	AE04CF	RCH205	K35R	62-3537	FFBD8D3CBFFCF8	FFBD8D3CBFFCF8	EB0A0734A007FE
98	8	11:07:23.41	AE04CF	RCH205	K35R	62-3537	**CE267130A60107**	FF9D873D7FFCF8	**CE267130A60107**
6	3	11:15:26.45	AE04CF	RCH205	K35R	62-3537	FF7D7B387FFCE2	FF7D7B387FFCE2	EAFA072F3F17E0
6	3	11:19:58.32	AE04CF	RCH205	K35R	62-3537	801D73316004C7	801D73316004C7	EA9A1D297E27C8
6	3	11:27:51.47	AE04CF	RCH205	K35R	62-3537	803B8F25A004A0	803B8F25A004A0	DD19F9203BE786

In this second example detected with aircraft “3F9AC4”, which is a civil aircraft, the BDS 40 and 50 have the same value (in red). The problem exists with all permutations of BDS number including 10, 20, 17 and others.
The occurrence of the problem could be around four to ten minute.

time	sac	sic	ModeS	ACID	typ	modeA	modeC	BDS40	BDS50	BDS60	BDS10	BDS17
11:00:57.78	6	5	3F9AC4	GAF695	RC	A1354	17625				10010680F60000	
11:01:09.62	6	5	3F9AC4	GAF695	RC	A1354	17325					FA810100000000
11:01:21.46	6	5	3F9AC4	GAF695	RCP	A1354	17025	97700030AA0000	80599726201CAE	CCCA21233E87D0		
11:01:33.29	6	5	3F9AC4	GAF695	RCP	A1354	16750	97700030AA0000	FFF999263FFCAF	CCCA27237E9FD3		
11:01:45.12	6	5	3F9AC4	GAF695	RC	A1354	16450	97700030AA0000	FFF997267FFCAF	CCCA29237E8FD2		
11:01:56.94	6	5	3F9AC4	GAF695	RCP	A1354	16150	97700030AA0000	FFF99526600CB0	CCDA2F237EAFD3		
11:02:08.79	6	5	3F9AC4	GAF695	RCP	A1354	15875	97700030AA0000	80199526600CB0	CCFA3323BE77D1		
11:02:20.65	6	5	3F9AC4	GAF695	RC	A1354	15575	97700030AA0000	803999267FF4B0	CD0A35237E97D0		
11:02:32.48	6	5	3F9AC4	GAF695	RC	A1354	15275	97700030AA0000	801999263FFCB0	CD1A35237E97D2		
11:02:44.32	6	5	3F9AC4	GAF695	RCP	A1354	15000	97700030AA0000	FFD99B263FF4AE	CD0A3322FE97D2		
11:02:56.15	6	5	3F9AC4	GAF695	RCP	A1354	14700	97700030AA0000	FFF99B262004AD	CD0A3122BE97D2		
11:03:07.99	6	5	3F9AC4	GAF695	RCP	A1354	14400	97700030AA0000	FFD999263FFCAB	CCFA2D223E87D1		
11:03:19.84	6	5	3F9AC4	GAF695	RCP	A1354	14100	97700030AA0000	FFF999262014AB	CCFA2F223E97D2		
11:03:31.69	6	5	3F9AC4	GAF695	RC	A1354	13825	97700030AA0000	FFD997263FFCAB	CD0A33223E87D2		
11:03:43.52	**6**	**5**	**3F9AC4**	**GAF695**	**RCP**	**A1354**	**13525**	**80399525E00CAA**	**80399525E00CAA**	**CD0A3121FE9FD2**		
11:03:55.36	6	5	3F9AC4	GAF695	RCP	A1354	13225	97700030AA0000	80999526201CA9	CD2A3121BEA7D0		
11:04:07.20	6	5	3F9AC4	GAF695	RCP	A1354	12950	97700030AA0000	807995262004A7	CD4A2B217E9FD3		
11:04:19.03	6	5	3F9AC4	GAF695	RCP	A1354	12650	97700030AA0000	FFD999263FE4A6	CD4A29213E7FD2		
11:04:30.87	6	5	3F9AC4	GAF695	RCP	A1354	12350	97700030AA0000	801997263FFCA5	CD5A2920FE77D2		

This third example shows the BDS swap with BDS 10 and a repetition rate varying from 5 minutes to 30 minutes.

6	5	12:48:30.21	3C9AC7	DBFVG	117.61	83.08	100000008000FF	100000008000FF
6	5	16:31:13.61	3C9AC7	DBFVG	117.61	83.06	100000008000FF	100000008000FF
6	5	16:40:54.07	3C9AC7	DBFVG	117.62	83.06	100000008000FF	100000008000FF
6	5	17:09:54.36	3C9AC7	DBFVG	117.61	83.07	100000008000FF	100000008000FF
6	5	17:44:37.60	3C9AC7	DBFVG	117.61	83.06	100000008000FF	100000008000FF
6	5	18:54:27.61	3C9AC7	DBFVG	117.61	83.06	100000008000FF	100000008000FF
6	5	19:24:39.09	3C9AC7	DBFVG	117.61	83.1	100000008000FF	100000008000FF
6	5	19:38:27.40	3C9AC7	DBFVG	117.61	83.07	100000008000FF	100000008000FF
6	5	20:05:52.66	3C9AC7	DBFVG	117.61	83.08	100000008000FF	100000008000FF
6	5	20:07:27.39	3C9AC7	DBFVG	117.62	83.07	100020008000FF	100020008000FF
6	5	20:43:09.84	3C9AC7	DBFVG	117.61	83.06	100000008000FF	100000008000FF
6	5	20:52:37.70	3C9AC7	DBFVG	117.61	83.08	100000008000FF	100000008000FF
6	5	21:12:09.52	3C9AC7	DBFVG	117.61	83.1	100000008000FF	100000008000FF
6	5	21:27:32.52	3C9AC7	DBFVG	117.62	83.13	100020008000FF	100020008000FF

Under the pressure of cases reported from all mode S sites, AMP started the first investigations end of 2009 and beginning of 2010. From the different ideas hold for the analysis the more credible was related to a conflict of interrogations at the transponder level. AMP took this assumption to define an approach and propose a measurement campaign.

2) Theoretical approach

A) Simultaneous interrogation

The theoretical approach is to consider a collision of two interrogations with different amplitude issued by two different Mode-S radars arriving practically at the same time at the input of the transponder.

A transponder validates the mode-S interrogations in two manners :

- Validation of P1,P2 and P6 pulses
- Validation of the Synchro-Phase reversal (SPH).

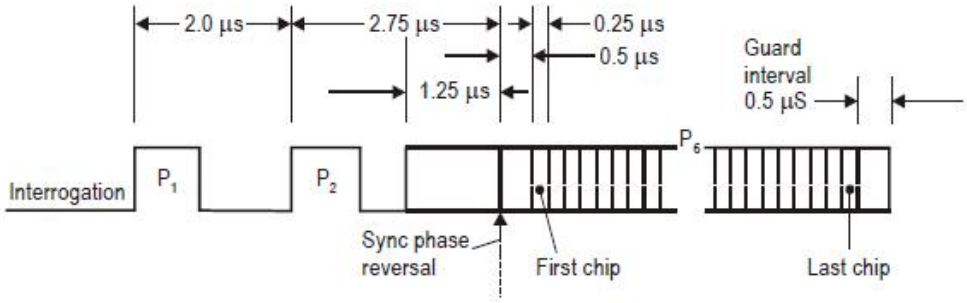


Figure 2 : Mode-S interrogation pulse pattern

That means that we have to consider the position of P1, P2, and P6 pulses of the second interrogation in rapport of the SPH position of the first interrogation which will be the reference interrogation.

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The different situations are summarized in the below drawing.

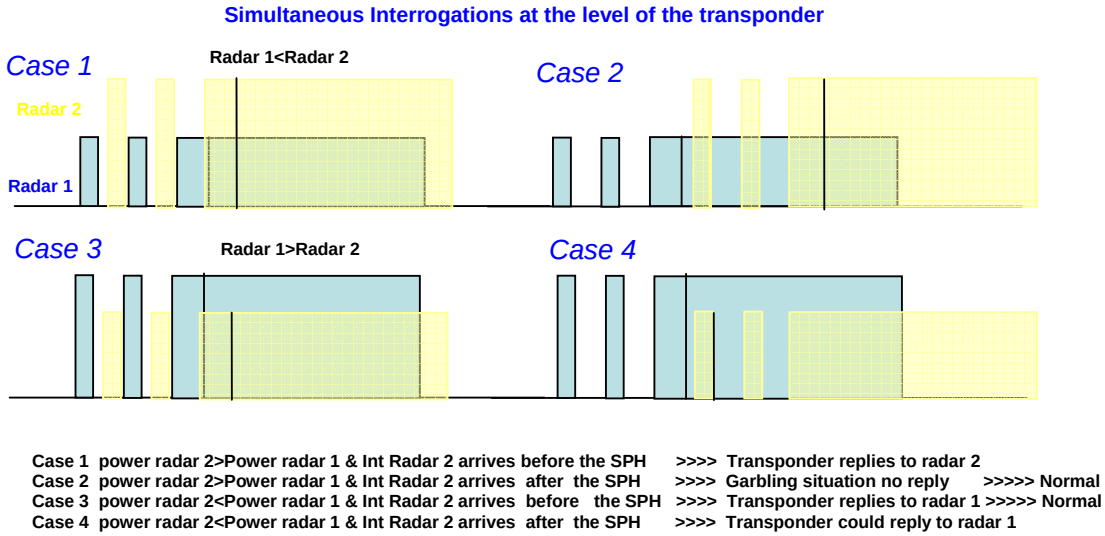


Figure 3 : Four possible cases

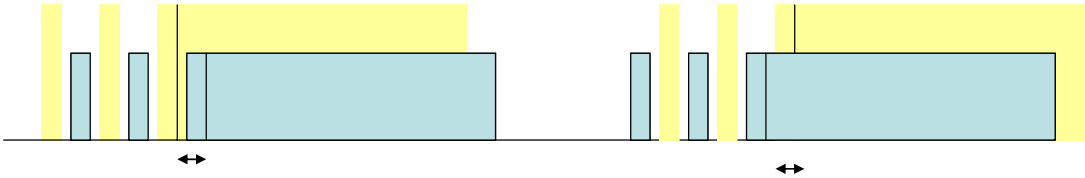
Case 1: the reference interrogation is in blue. After reception of P1 pulse the transponder receives a second interrogation with higher amplitude. The transponder will reply on this second interrogation and the radar number 1 will receive a reply requested by radar number 2. It is a pure FRUIT situation which corresponds to our problem.

Case 2 : the transponder receives P1 P2 and P6 pulse of the radar 1 and validate the synchro-phase reversal. If after the SPH a stronger signal arrives it will be in a garbling situation and probably the transponder will not reply. This situation is normal.

Case 3 and 4: the transponder receives the interrogation from radar 1 and after receives a second lower interrogation from radar 2, the transponder is not desensitized by the second interrogation and will reply to radar 1.

In summary the FRUIT situation arrives when the second interrogation is stronger than the first and when the occurrence of this second interrogation is before the SPH. The time between the leading edge of P1 pulse and the SPH is 4.75 µsec.

If the interrogation has an advance on time of more than 4.75 µs, the delta T will be negative. If the second interrogation has a delay from the reference interrogation, then the delta T will be positive.



Delta T will be <0 **Figure 4 : Delta T** Delta T will be >0

As the transponder doesn't receive both interrogations at the same time, this delta T will be the same between the two replies. This difference of time will be between 1 µs to 4.75 µs maximum and should be measured at the reply level. If the value of this delta T is greater than 4.75, then the transponder will be in garbling situation and should not reply. The negative values could vary from -1 µs to -X µs where X is corresponding to the dynamic time window opened to receive a reply and is different for each radar. This value should be less than -10 µs.

Hypothesis 1: the occurrence of the BDS swap will be detectable with a delta T between - 10µs to +4.75 µs.

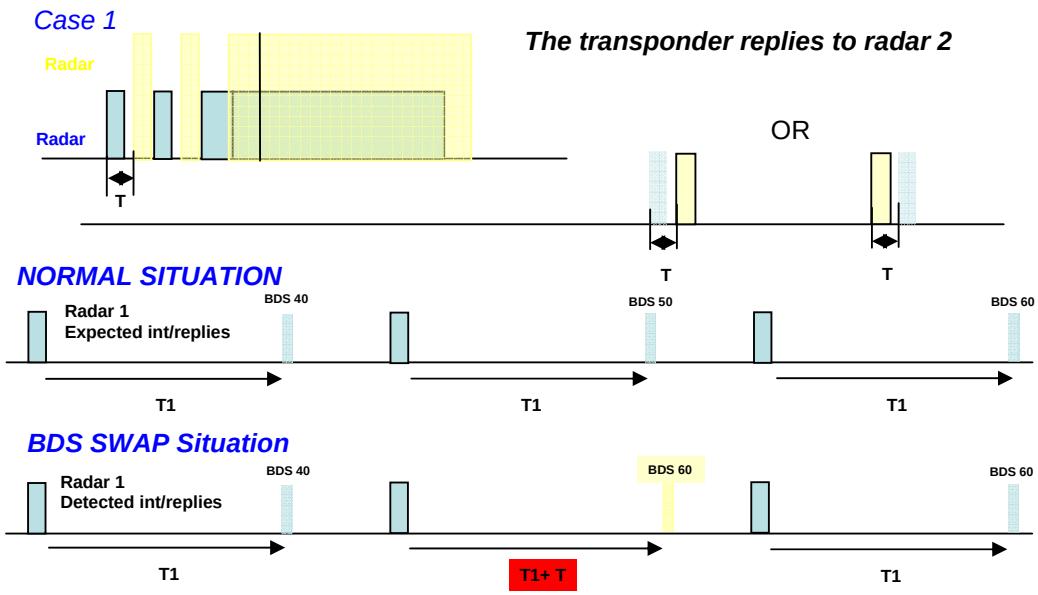


Figure 5 : FRUIT situation in case of BDS swap

Figure 5 shows the sequence of interrogations of Mode-s radar. The duration of this sequence is about 15 ms and during this period the radar is generating different types and number of interrogations. For one aircraft, if we compare the time between each interrogation and its corresponding reply during all the sequence (delta T), the delta T for each couple interrogation/reply is almost the same at +- 100 ns.

When the radar extracts the BDS 40, 50 and 60, it is done with three successive interrogations either in the same sequence or in two consecutive sequences.
In particular case of the BDS swap issue the hypothesis is that the delta T will be different and this difference will be detectable and measurable at the level of several µs.

Hypothesis 2: For one aircraft without FRUIT situation, delta T is a constant value at about +-100 ns. This is the time between each interrogation and its corresponding reply during all a sequence of interrogations.

We based our measurement campaign at BERTEM radar in Belgium on these two assumptions and our objective was to verify the existence of this delta T in case of BDS swap

B) Periodicity of the problem

The report released by BELGOCONTROL shows that the problem could appear at different time periods. These periods vary between 30 seconds to several minutes. **So the plurality of situations shows the complexity of the problem**.

The periodicity of simultaneous occurrence of beams of two radars is depending only of their rotating period. This situation is given in first approximation by the following formula: T= T1(1-T1/Delta T) where T1 is the period of radar 1 and Delta T = T1-T2. The following table gives the time in second between a collision of two interrogations issued by two radars with a turn rate between 11 and 12 seconds.

The periodicity of collision of two interrogations can be between 2 to 30 minutes. With a turn rate at BERTEM of 11.8 second and a radar around 11.5 second the periodicity is around 452 second either around 7 minutes.

	11	11,1	11,2	11,3	11,4	11,5	11,6	11,7	11,8	11,9
11	-									
11,1	1221,0	-								
11,2	616,0	1243,2	-							
11,3	414,3	627,2	1265,6	-						
11,4	313,5	421,8	638,4	1288,2	-					
11,5	253,0	319,1	429,3	649,8	1311,0	-				
11,6	212,7	257,5	324,8	436,9	661,2	1334,0	-			
11,7	183,9	216,5	262,1	330,5	444,6	672,8	1357,2	-		
11,8	162,3	187,1	220,3	266,7	336,3	452,3	684,4	1380,6	-	
11,9	145,4	165,1	190,4	224,1	271,3	342,1	460,1	696,2	1404,2	-
12	132,0	148,0	168,0	193,7	228,0	276,0	348,0	468,0	708,0	1428,0
12,1	121,0	134,3	150,6	170,9	197,1	231,9	280,7	353,9	475,9	720,0

Figure 6 : Periodicity of collisions

This table gives the periodicity of occurrence of radar conjunction area which exists during brief time duration (some seconds) but appears periodically. Aircraft has to be in this area to meet the FRUIT problem. As the aircraft is moving the probability to have these conjunctions (Radars and aircraft) should be very low and effectively we detected this situation one or two times maximum for civilian aircraft:

- this periodicity has been detected with the Boeing KC135 military
- this periodicity has not been observed for civilian aircraft for which only one BDS swap case has been recorded per aircraft.

3) BERTEM measurements

A measurement campaign was held with BELGOCONTROL at BERTEM Mode-S radar on the 17 and 18 February 2010.

a- measurements conditions

The main objective of this measurement was to detect BDS swap situations and to verify the time between Mode S interrogations and Mode S replies.

In this objective the measurement chain puts in place the following installation.

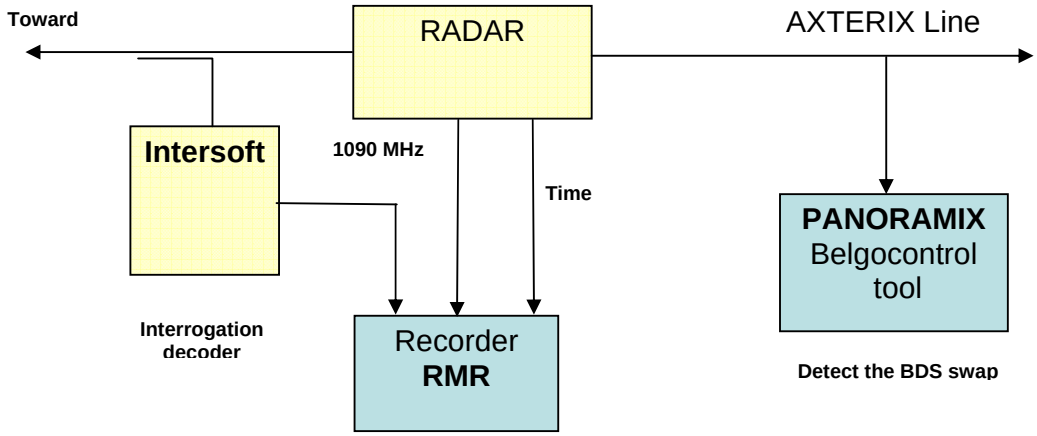


Figure 7 : Measurement chain at BERTEM Mode S radar

The principle was to record during a long period and after look for the swap situation in the records

<u>To record the 1090 MHz video signal</u> of the transponder replies: this is done with RMR recorder provided by Eurocontrol connected to the 1090 video output connector of the BERTEM Mode-S radar with a capability of 6 hours of recordings. This recording was done all day long per slot of 1 minute to capture the video signal of a BDS swapping cases. Due to the amount of the data, we need to analyse only a part of the video file where the problem occurred.

To record the 1030 MHz video signal of the interrogations of the mode-S radar:
The interrogations were detected at the antenna cable level via a coupler and attenuation chain and connected to an INTERSOFT RF analyzer. This last tool gives the detail of the interrogations transmitted.

<u>To record ASTERIX radar stream and detect BDS swapping</u> : this is done with PANORAMIX to record ASTERIX data and decode to identify the time slot where the BDS swapping occurred
BELGOCONTROL developed an ASTERIX recorder / analyzer named **PANORAMIX** able to detect and summarizes automatically the BDS swap cases.

At each level the time is recorded with an accuracy of 100 ns.

The BERTEM interrogation sequence is the following:

DF=20 with BDS 60, DF=21 with BDS 50 and DF=20 with BDS 40

b- Analysis

The records had been done on the 17 February and the 18 February. The recorder was programmed to record files of one minute during six hours.

From PANORAMIX tool the following BDS swap situation were detected. The table below reveals immediately two situations:

- The Boeing KC135 military flights with a repetition of the problem very often (some seconds to several minutes)
- Other civil aircraft with only one occurrence from time to time

We obtained a list of 14 cases to base our analysis and verify the time difference between the interrogations/replies.

EVENTS	ACID	Address	Type	Date	Hour	intersoft
1	DLH	3C4E47		17-Feb	13:13:40	N
2	AEA	3412CA		17-Feb	16:42:13	N
3	RCH	AE04C6	**KC135**	17-Feb	20:41:55	N
4	RCH	AE04C6	**KC135**	17-Feb	20:51:12	N
5	QID	AE064E	**KC135**	18-Feb	13:25:59	Y
6	QID	AE064E	**KC135**	18-Feb	13:32:31	Y
7	QID	AE064E	**KC135**	18-Feb	13:36:52	Y
8	QID	AE064E	**KC135**	18-Feb	13:38:26	Y
9	QID	AE064E	**KC135**	18-Feb	13:40:01	Y
10	QID	AE064E	**KC135**	18-Feb	13:50:06	Y
11	BEE	405C0F		18-Feb	15:37:41	Y
12	BAW	4007F6		18-Feb	15:48:58	Y
13	TYW	440CC2		18-Feb	17:46:01	Y
14	HLX	3C60C9		18-Feb	23:19:02	Y

Figure 8 : Cases of BDS swap

- Measurement method

With the PANORAMIX tool the BDS swaps are identified with the aircraft address and with the corresponding time. For each cases three analysis are presented:

1) **PANORAMIX Analysis**: Each time we present three cases with the case number 2 having the BDS swap problem. The two other cases are used as a reference
2) **INTERSOFT Analysis** gives the detail of the interrogation : Which UF used and which BDS requested for extraction
3) **RMR Analysis** gives the time between interrogation and reply, the DF format used and the extracted BDS message.

The case 1, is corresponding to several interrogations in a sequence and each interrogation is indicated by items a, b, c etc. The same items are reproduced in RMR replies recording corresponding to the replies.

We can verify that for case 1, the time difference between the interrogations and the replies is always 1299 +/- 100 ns. In this case we have not FRUIT problem. The same analysis performed on case 3 gives the same conclusion.

Research of the time difference

(Analyse Panoramix)

	time	ModeS	ACID	modeA	modeC	BDS40	BDS50	BDS60	
case 1)	15:37:30.02	405C0F	BEE7266	A2517	24000	AEE00000000000	FFBC6D278004AA	E1E9E523FFEFFF	
case 2)	15:37:41.86	405C0F	BEE7266	A2517	24000	**FF9C6F278004AB**	**FF9C6F278004AB**	E1E9E724200C01	BDS40 = BDS50
case 3)	15:37:53.70	405C0F	BEE7266	A2517	24000	AEE00000000000	FFBC6F274004AA	E1E9E323FFC401	

(Analyse RMR)

The swap problem is detected with the case 2

(case 1) sequence ,,

= Intersoft interrogations recording =
a) ti= 15:37:29.856 792 UF=4:PC=0:RR=22(BDSx60)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=405C0F
b) ti= 15:37:29.870 215 UF=5:PC=0:RR=21(BDSx50)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=405C0F
c) ti= 15:37:29.870 614 UF=5:PC=0:RR=20(BDSx40)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=405C0F
d) ti= 15:37:29.883 646 UF=5:PC=0:RR=0:DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=405C0F
= RMR replies Recording ==
a) T=39.2233 DTIR= 1230.051 µs DF BDS60
b) T=39.2367 DTIR= 1229.990 µs DF BDS50
c) T=39.2371 DTIR= 1229.975 µs DF BDS40
d) T= DTIR= µs DF BDS
conclusion : OK

In this case the relative delta T is always < 100 ns

The analysis of case 2 where a BDS swap has been detected gives different results.
The time for two replies is around 1242 µs +/- 100 ns but for the last with a time of 1244.2 µs either a time difference **of 1.7 µs. This situation confirms that the reply is corresponding to a FRUIT.**

Research of the time difference

(case 2) sequence 60,50,

= Intersoft interrogations recording =
a) ti= 15:37:41.698 898 UF=4:PC=0:RR=22(BDSx60)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=405C0F
b) ti= 15:37:41.712 190 DT= 13292 UF=5:PC=0:RR=21(BDSx50)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=405C0F
c) ti= 15:37:41.712 590 DT= 400 UF=5:PC=0:RR=20(BDSx40)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=405C0F
d) ti= 15:37:41.725 600 DT= 13010 UF=5:PC=0:RR=0:DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=405C0F

= RMR replies Recording ==
a) T=51.0457 AEE00000000 DTIR= N/A DF20 BDS? No interrogation
b) T=51.0653 E1E9E724200C01 DTIR= 1242.5 µs DF20 BDS60 OK reply to interrogation a)
c) T=51.0786 FF9C6F278004AB DTIR= 1242.550 µs DF21 BDS50 (-36Dbm) OK reply to interrogation b)
d) T=51.0790 FF9C6F278004AB DTIR= 1244.200 µs DF20 BDS50 (-52 Dbm) critical case reply to interrogation c)

Delta T = 50 ns

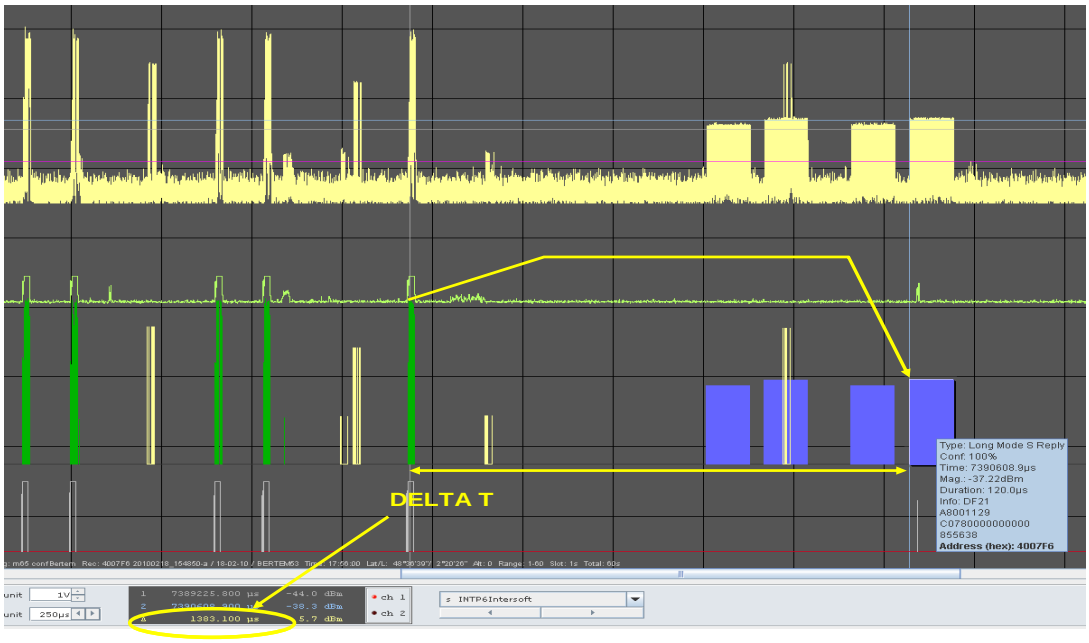
Delta T = 1.7µs

Interrogation C requires reply with DF =21 (UF=5) and we receive DF=20
The radar doesn't verify the label of the reply

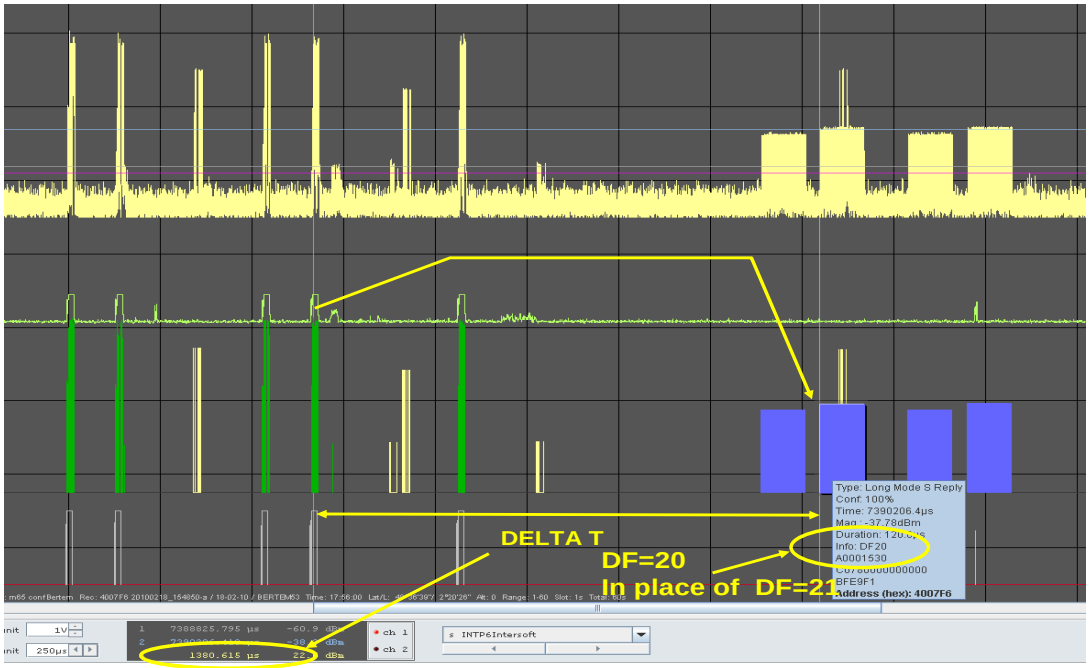
The detailed analysis reveals also that the first interrogation is done with UF = 4 and request a DF=20 reply with a BDS=60. It is what we obtain.

The second interrogation is done with UF=5 and requests a DF=21 with a BDS 50. It is what we obtain.

The third interrogation is done with UF=5 and requests a DF=21 with a BDS =40**. We obtain a DF=20 and BDS=50** and the time difference is not correct. In this last case the radar accept the DF=20 which should be rejected.



Picture 1



Picture 2

In the example presented above the delta Time is 1383.1 µs. in picture 1 and the delta T is 1380.6 µs with picture 2 either a difference of -2.5µs. The DF decoded is not DF21 as in the previous picture but DF=20 corresponding to the message reported in the ASTERIX line. **The radar doesn't verify the label of the reply**.

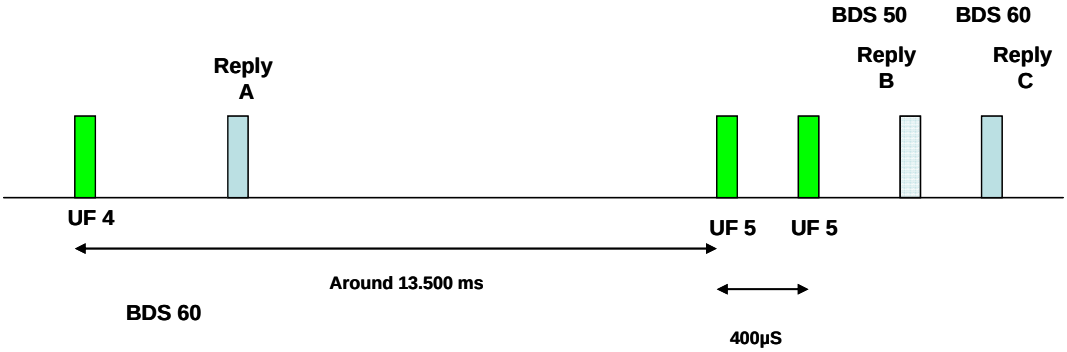
We performed the analysis on the 14 cases and we obtain the following tables related to civil flight and military flights giving a clear situation:

Civil Flights

ACID	Address	Date	Hour	DT i-r
DLH	3C4E47	17-Feb	13:13:40	-4,17 µs
AEA	3412CA	17-Feb	16:42:13	-5 µs
BEE	405C0F	18-Feb	15:37:41	+1,7µs
BAW	4007F6	18-Feb	15:48:58	-2,5µs
TYW	440CC2	18-Feb	17:46:01	-2µs
HLX	3C60C9	18-Feb	23:19:02	-1,8µs

All these cases are perfectly corresponding to the theory presented above with a delta T varying from -10 µs to +4.75 µs and with positive and negative values.

The interrogation sequence used at BERTEM is the following.



The swap problem has been detected on replies B and C in a similar occurrence.

EVENTS	ACID	Address	DT i-r	DF21	Reply Type
1	DLH	3C4E47	-4,175 µs	Receive DF20	**B**
2	AEA	3412CA	-5 µs	Receive DF20	**B**
11	BEE	405C0F	+1,7µs	Receive DF20	**C**
12	BAW	4007F6	-2,5µs	Receive DF20	**B**
13	TYW	440CC2	-2µs	Receive DF20	**C**
14	HLX	3C60C9	-1,8µs	Receive DF20	**C**

Probably the problem exists also with reply A but the case has not been detected during our measurement period.

The FRUIT situation results of replies requested by other radar. In our case this second radar is probably German radar. This radar is making extraction always with UF=4 and the corresponding replies are always DF20. The BERTEM radar is using UF 4 only for the first interrogation this means that we don't detect the DF label error on the first interrogation.

The BDS swap should be present in all BDS extraction and not only on BDS 60; 50; 40.

The same process performed on military flights gives the following table:

The radar problem detected during this campaign is not linked with the FRUIT. But all cases analyzed during this campaign show that if the radar rejected as it have to do the bad DF all these FRUIT situations will be filtered and rejected.

We request to perform additional test with other types of radar to verify this point or at least to determine the probability of occurrence of BDS swap.

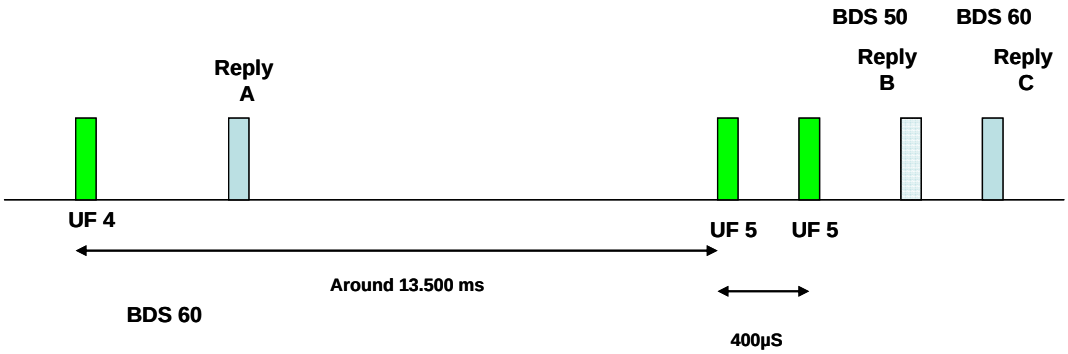
Military Flights

EVENTS	ACID	Address	Type	Date	Hour	DT i-r	DF20
3	RCH	AE04C6	KC135	17-Feb	20:41:55	0	OK
4	RCH	AE04C6	KC135	17-Feb	20:51:12	0	OK
5	QID	AE064E	KC135	18-Feb	13:25:59	0	OK
6	QID	AE064E	KC135	18-Feb	13:32:31	0	OK
7	QID	AE064E	KC135	18-Feb	13:36:52	0	OK
8	QID	AE064E	KC135	18-Feb	13:38:26	0	OK
9	QID	AE064E	KC135	18-Feb	13:40:01	0	OK
10	QID	AE064E	KC135	18-Feb	13:50:06	0	OK

For the military flights the delta T never exists. **The problem is not due to the FRUIT and necessitates a specific analysis.**

C- KC135 Cases analysis

The BERTEM interrogation sequence used revealed that the BDS swap problem was always for military flight on reply B and this expected reply was always missing. See the scope picture below:



RAYTHEON TRANSPONDER KC135 aircraft

(Analyse Panoramix) xx:xx:xx.xx AE04C6 ACID= ModeA= ModeC=
---

time	ModeS	ACID	modeA	modeC	BDS40	BDS50	BDS60	
1) 13:39:49.98	AE064E	QID96	A0476	25700	A90D4870AC0107	FF9E6B2D7FFCB9	F0FA0326FE5FCF	
2) 13:40:01.84	AE064E	QID96	A0476	25300	FFDE6B2DBFFCB9	FFDE6B2DBFFCB9	F13A0726FE2FC9	BDS40 = BDS50
3) 13:40:13.69	AE064E	QID96	A0476	25000	A90D4870AA0107	FF5E6D2DBFF4B9	F13A0B26FE5FCB	

This table represents the ASTERIX data where the problem is detected

(case 2) sequence ,,

= Intersoft interrogations recording = This data are detected at the level of the transmitter output and are representative of all interrogation transmitted by the radar.

a) ti= 13:40:01.679 130 UF=4:PC=0:RR=22(BDSx60)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=AE064E
b) ti= 13:40:01.692 547 DT= 13417 UF=4:PC=0:RR=22(BDSx60)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=AE064E
c) ti= 13:40:01.706 035 DT= 13488 UF=4:PC=0:RR=22(BDSx60)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=AE064E
d) ti= 13:40:01.719 439 DT= 13404 UF=5:PC=0:RR=21(BDSx50)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=AE064E
e) ti= 13:40:01.719 839 DT= 400 UF=5:PC=0:RR=20(BDSx40)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=AE064E
f) ti= 13:40:01.733 280 DT= 13441 UF=5:PC=0:RR=21(BDSx50)::DI=1:IIS=8:MBS=0:MES=0:LOS=1:RSS=0:TMS=0:AA=AE064E

= RMR replies Recording == Detected at the output of the radar receiver.
a) No reply
b)T=8.8824 F13A0726FE2FC9 DTIR= 1534.350 µs DF20 BDS60 OK reply to b)
c) T=8.8959 F13A0726FE2FC9 DTIR= 1534.350 µs DF20 BDS60 OK reply to c)
d) **No reply with DF=21**
e) T=8.9097 FFDE6B2DBFFCB9 DTIR= 1534.40 µs DF21 BDS50 reply to e)
f) T=8.9232 FFDE6B2DBFFCB9 DTIR= 1534.350 µs DF21 BDS50 reply to f)

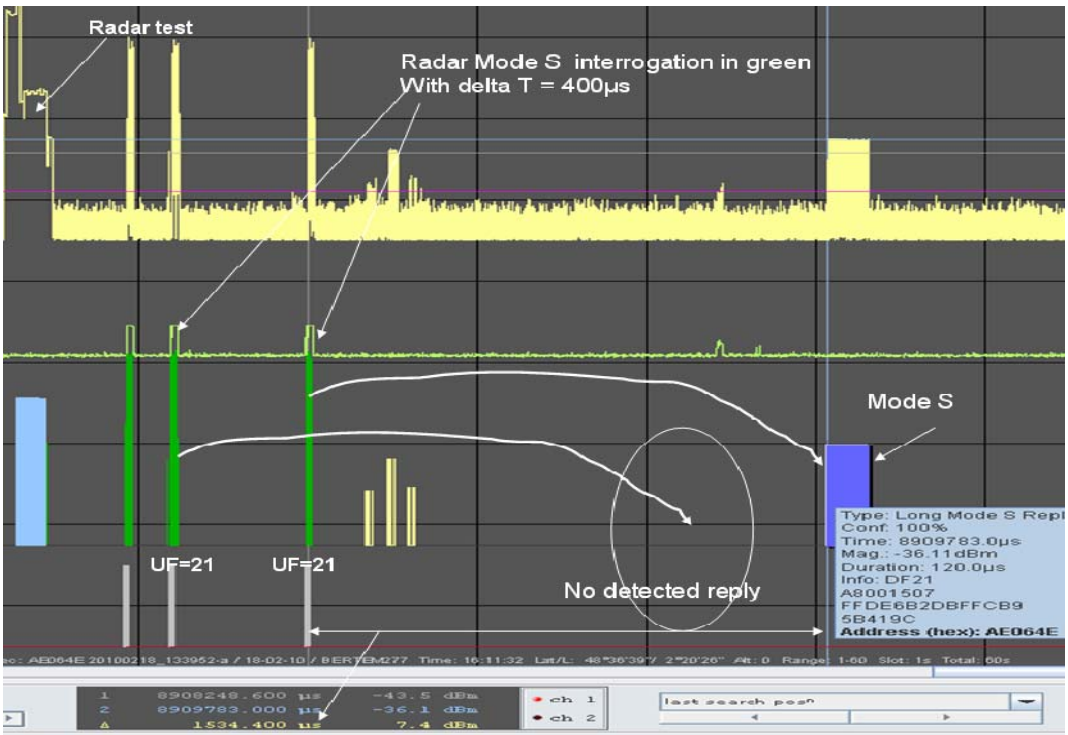
We analyze only the case 2 which is with the BDS swap problem.

If we consider the sequence detected by Intersoft tool we have the following interrogations:

a) first interrogation with UF=4 but in this case no reply
b) The radar repeats the interrogation with UF= 4 with request for BDS 60 we obtain DF=20 with BDS 60 Delta T = 1534.3µs OK
c) Third interrogation identical to the first and with the same result. Delta T = 1534.3 OK
d) Fourth interrogation UF=5 with request of BDS 50 no reply at the expected time.

e) 400 µs after the radar generates a fifth interrogation UF=5 with request for a BDS 40 **but we obtain BDS 50** with good delta T (1534.40µs OK)
f) The radar repeat UF=5 to extract the BDS 50 as no reply received in d and again with a good delta T (1534.5µs OK)

EVENTS	ACID	Address	Type	Date	Hour	DT i-r	DF20	Problem on:
3	RCH	AE04C6	KC135	17-Feb	20:41:55	0	OK	**B**
4	RCH	AE04C6	KC135	17-Feb	20:51:12	0	OK	**B**
5	QID	AE064E	KC135	18-Feb	13:25:59	0	OK	**B**
6	QID	AE064E	KC135	18-Feb	13:32:31	0	OK	**B**
7	QID	AE064E	KC135	18-Feb	13:36:52	0	OK	**B**
8	QID	AE064E	KC135	18-Feb	13:38:26	0	OK	**B**
9	QID	AE064E	KC135	18-Feb	13:40:01	0	OK	**B**
10	QID	AE064E	KC135	18-Feb	13:50:06	0	OK	**B**



With KC135 we have the following conclusions:

- The second reply is always missing
- No time difference between the different interrogations- replies
- The value of the extracted BDS in case (e) is what was requested in the previous interrogation and corresponds at the value of the missing reply.

The second point proves that this case is not corresponding to a FRUIT situation. The report of the BDS value of the missing reply in the next reply is corresponding to an index problem internally to the transponder and our conclusion suggested a real transponder problem.

The manufacturer has been contacted immediately and two days after confirmed the problem. A fix has been prepared and now the retrofit is on going.

FAA reported BDS swap problems. It was curious because FAA extracts BDS with radar in US and in these conditions it was difficult to meet the FRUIT problem. In fact as the majority of reports coming from Europe, this problem was due to the military aircraft KC135.

4) BROCKEN Measurements

After the measurements performed at BERTEM it was necessary to confirm the FRUIT situation with a different radar type. For availability raison the DFS proposed to make this analysis with the Mode S radar based at BROCKEN situated at the east of HANOVER. The campaign started the 12/10 on two days.

The recorder was directly connected to the video test connector of the radar. The recoding has been done permanently with files of one minute. The recorder was synchronized in time with GPS and DFS from LANGEN sent the log with the list of flight having BDS swap and the value of BDS. With the time marker it was easy to find the corresponding file. However during this recording campaign it was not possible to have access to the interrogations information.

The recording sessions were the following:

date	Hours		Nbr	Nbr/H
12-Oct	09:10	11:01	9	4,86
12-Oct	13:10	20:01	18	2,63
13-Oct	06:43	08:52	7	3,31
			Mean	3,60

With an average value of 3.6 BDS swap per hour, this represents around 1200 cases per month. In comparison, the situation at BERTEM was around 300 per month.
As at BERTEM our objective was to detect the time differences between interrogation/reply in the successive sequences in the beam.
The table below summarizes the situation:

EVENTS	ACID	ADDRESS	DATE	HOUR	Delta T
1	EIN 837	4CA6C4	12-Oct	10H09:52	**-8,5µs**
2	BER677J	3C7262	12-Oct	10H33:18	**-7,5µs**
3	FIN782R	4248ED	12-Oct	10H48:52	**-4µs**
4	GAF690	3FB0AE	12-Oct	11H39:17	**0**
5	GAF690	3FB0AE	12-Oct	13H10:56	**0**
6	RYR7XW	4CA27A	12-Oct	13H22:21	**-5,25µs**
7	DLH084	3C4943	12-Oct	15H14:56	**-9,9µs**
8	FIN707S	461F32	12-Oct	15H51:20	**-8,4µs**
9	AFR1945	391552	12-Oct	15H51:50	**-4,4µs**
10	N52DC	A686E3	12-Oct	16H34:45	**-4,7µs**
11	PGT362	4B842B	12-Oct	17H21:44	**-8µs**
12	DLH164	3C6665	12-Oct	17H27:04	**-5,7µs**
13	BER115R	440319	12-Oct	17H29:37	**-7,3µs**
14	DLH933	3C662D	12-Oct	17H52:39	**+2,2µs**
15	DLH1RV	3C48A2	12-Oct	18H22:37	**+2,2µs**
16	CMB534	AA51DF	12-Oct	19H16:35	**0**
17	THY1979	4BA88A	13-Oct	8H23:21	**-5,2µs**
18	GAF677	3F7490	13-Oct	8H42:38	**0**
19	RYR4891	4CA224	12-Oct	18H52:18	**+2,2µs**

From the 19 studied cases 15 give a time difference between 2.2 µs to – 9.9 µs. These time differences are in line with the results obtained during the BERTEM campaign and confirm the importance of the FRUIT in the BDS extraction.

However with this type of radar we can say that the tracking window is larger:

BERTEM : -5.7 µs to 2µs
BROCKEN: -9.9 µs to 2.2 µs

This large window could explain partially the high number of flight with BDS swap at BROCKEN.

Four cases have been detected with no difference in time (Delta T =0). Three are from the German Air Force using the same type of transponder. A case is seen two times, the same day, with the same problem. This situation could suggest a transponder problem and shall be verified.

The fourth case is a civil aircraft which can not be explained excepted if we consider that the two interrogations arrive at the transponder level at the same time +- 50 ns. A large analysis done on different German radar shows that many civil aircraft present systematically the same problem at few hours of interval. It is difficult to admit two simultaneous interrogations to explain these different cases.
A new campaign of measurement could be useful to understand the problem but at the condition to have access to the interrogation data.

5) Conclusions

The detection of the BDS swap in several places in Europe and in US has been confirmed by measurement campaigns performed by EUROCONTROL at BERTEM radar with BELGOCONTROL. At BERTEM , three problems has been discovered:

- **A real FRUIT problem impacting the Mode S system**
- **A military transponder problem**
- **A radar problem which don't filter correctly the DF format.**
-

Additional measurement performed at BROCKEN with DFS radar confirmed the FRUIT Problem during the BDS extraction.