Investigation of the interaction between different avalanche transceivers in multiple burials

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Summer 2006

Avalanche transceivers are becoming ever more complex with each generation, not least in order to overcome the problems associated with multiple burials. For the first time in this study, the reasons underlying the "problems associated with multiple burial" were investigated both through a programme of laboratory tests and a brief theoretical treatment, and it was evident that altogether different approaches to this topic have been adopted by the various avalanche transceiver manufacturers, whether deliberately or not.

Background:

Now that the problem of multiple maxima has been solved by the introduction of triple antenna technology, the problem of multiple burials still remains as the "last great challenge" to the next generations of avalanche transceivers. Limitations, both physical and in terms of standards, as well as the prevailing market penetration by "old" devices, militate against a satisfactory resolution of this problem. The fact is that occurrences of multiple burials of at least two victims lying near to each other constitute a large proportion of all burials, requiring serious consideration. Data on avalanche accidents in the Swiss Alps from 1970-1999 provided by SLF in Davos were analysed and published in a study in 2000. A large number of papers, also on the topic of multiple burials and based on these data, were published. Of greatest interest for this study are the statistics of multiple burials:

Number of burials	Number of accidents	Number of affected people	Number of accidents [%]	Affected People [%]
1	339	339	72.75	48.57
2	72	144	15.45	20.63
3	27	81	5.79	11.60
4	15	60	3.22	8.60
5	7	35	1.50	5.01
6	4	24	0.86	3.44
7	1	7	0.21	1.00
8	1	8	0.21	1.15
Total	466	698	100.00	100.00

Table1: Numbers and percentages of accidents and victims involved in multiple burials (completely buried with no visible equipment on surface, from 1970 to 1999), source: SLF Davos, 2000

A clear picture emerges: accidents involving more than one buried victim are altogether frequent (27.25%). Indeed, on the basis of the number of people buried this rises to more than 50%.

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Standards and physical limits

The applicable standards oblige all manufacturers to ensure that their avalanche transceivers comply when transmitting signals. As with many standards, downward compatibility seems to the main yardstick, thus also having a significant and largely negative influence on the continued development of avalanche transceivers.

For the transmitted signal, with regard to transmission frequency, duration of repetition period and pulse, the standard permits large tolerances that fall well short of what is technically possible today, yet it allows no form of additional signal identification (modulation).

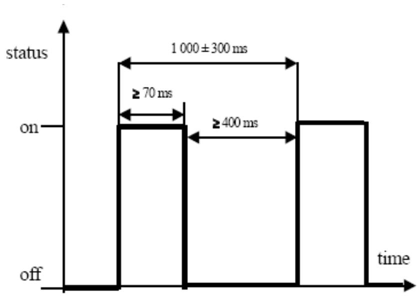

Figure1: Signal conforming with EN 300718 standard, signal form 1A1, pulse duration ≥70ms, repetition period 1000±300ms, pause ≥400ms

Ultimately the problem of "multiple burial" reduces to the case of two transmitters lying in immediate vicinity to one another and registering reception on an avalanche transceiver at almost identical signal strengths. This essentially results in frequent signal interference taking the form of signal modulation (alternating constructive and destructive interference of the signal), something that neither analogue devices (acoustic signal separation through human perception) nor highly developed digital devices (using signal analysis) can always discriminate unambiguously.

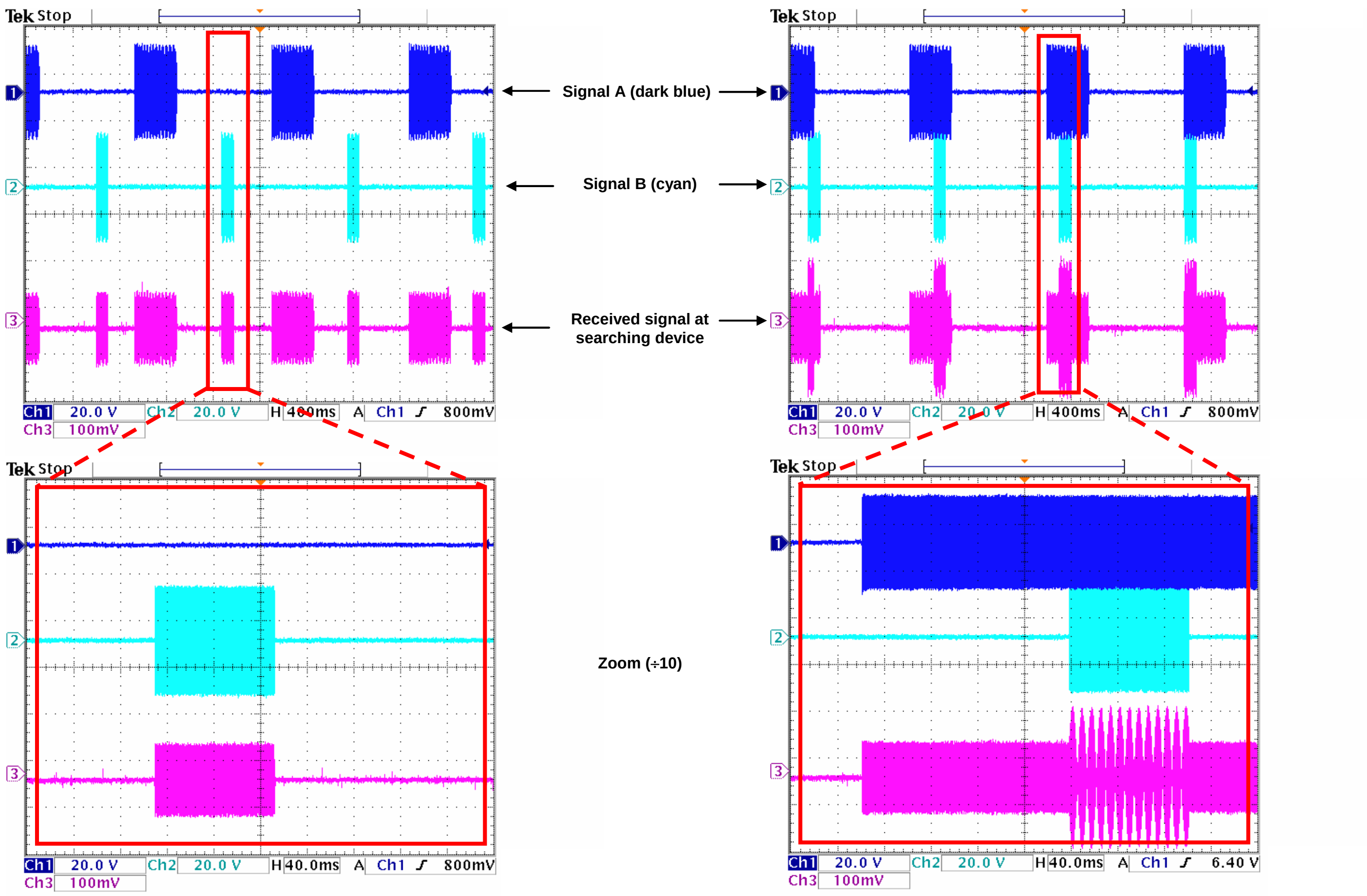

Figure 2:
Left: two different senders not overlapping at the instant of recording. The receiver can receive the two signals cleanly and separately. Yet different period durations give rise to regular overlap.
Right: the same two signals during overlap. Signal modulation and annihilation mean that the received signal cannot be measured correctly during overlap.

Proposition of the investigation:

This laboratory study was based on the proposition that two avalanche victims buried immediately next to each other constitute the worst-case scenario. Even recognising that accidents involving 3 or more buried victims still involve 30.8% of the people, one can assume that in these cases too, spatially extensive scenarios are involved which can be treated as several individual burials and, at most, double burials. We assume that treatment of a maximum of 2 buried victims in immediate proximity (we commit to the criterion 10m) will indeed cover around 95% of all accidents.

How the tests were conducted:

In order to permit simple recording of the transmitted signals, a simple direct receiver was constructed with a downstream Schmitt trigger. These signals were connected to a storage oscilloscope and passed via a data logger to be recorded on a PC. In order to speed up the test runs, three signals were always recorded at once. Using the data series (sampling rate 10ms), phases of signal overlap and separation were determined for all pairings. The calculation was performed by a small analysis program. The time series were analysed in such a way that both the beginning of overlap (as soon as more than one signal was received at once) and the end of overlap (when both signals were received separately again) were marked as phases of overlap. This "overlap" phase and resultant "separation" phase were calculated and added into the time series.

Figure4: test arrangement with three receiver modules, a storage oscilloscope (Tektronix TDS3014B)

Initially devices of the same model were tested together, with each test involving three test runs in order to take account of potential chance occurrences (effects of arbitrary switch-on time). In addition, all possible combinations of devices from different manufacturers were tested, again with three test runs in each case. The recording period for each individual test run was always exactly 10 minutes, on the one hand in order to reveal repeating overlap phases and, on the other hand, in order to represent a relevant search duration.

The devices that were tested:

A random selection of at least three examples of any particular model was drawn from a large collection of commercially available test and demo devices. First these devices were all measured individually and the fundamental transmitter parameters evaluated. Also, all test devices were furnished with new batteries.

Test device	Manufacturer / Model	Serial number	Frequency deviation. Standard: 457,000 ± 80 Hz	Repetition period Standard: 1000 ±300ms	Pulse duration Standard: ≥ 70ms	Pulse/pause ratio
A-1	Arva / Advanced	1D-0052-1109	+0 Hz	916 ms	74 ms	8.8%
A-2	Arva / Advanced	E-4604-1210	-2 Hz	890 ms	74 ms	9.1%
A-3	Arva / Evolution	2260	+3 Hz	890 ms	76 ms	9.3%
B-1	Barryvox / Opto3000	M0122375	-3 Hz	996 ms	102 ms	11.4%
B-2	Barryvox / Opto3000	M0122797	-1 Hz	968 ms	102 ms	11.8%
B- 3	Barryvox / Opto3000	M0049664	+7 Hz	1004 ms	102 ms	11.3%
P-1	Pieps / DSP	06048324620321	-5 Hz	960 ms	100 ms	11.6%
P-2	Pieps / DSP	06048324620357	-6 Hz	1020 ms	100 ms	10.9%
P-3	Pieps / DSP	06048324620383	-5 Hz	890 ms	100 ms	12.7%
T-1	Tracker / DTS	98618	+9 Hz	804 ms	96 ms	13.6%
T-2	Tracker / DTS	52279	+23 Hz	792 ms	94 ms	13.5%
T-3	Tracker / DTS	58767	+9 Hz	776 ms	94 ms	13.8%
V-1	Pieps / 457	98 99	-8 Hz	916 ms	100 ms	12.3%
V-2	Pieps / 457	10 06	1 Hz	890 ms	96 ms	12.1%
V-3	Pieps / 457	25 06	-7 Hz	890 ms	94 ms	11.8%
X-1	Ortovox / X1	444404	-7 Hz	868 ms	212 ms	32.3%
X-2	Ortovox / X1	454547	+5 Hz	880 ms	220 ms	33.3%
X-3	Ortovox / X1	347092	+18 Hz	804 ms	196 ms	32.2%
F-1	Ortovox / F1	821072	-40 Hz	1180 ms	366 ms	45.0%
F-2	Ortovox / F1	443745	-91 Hz	1210 ms	370 ms	44.0%
F-3	Ortovox / F1	747747	-79 Hz	1190 ms	388 ms	48.4%
M-1	Ortovox / M2	033201	-54 Hz	704 ms	108 ms	18.1%
M-2	Ortovox / M2	143766	-33 Hz	872 ms	104 ms	13.5%
M-3	Ortovox / M2	132864	-34 Hz	622 ms	112 ms	22.0%

Table2: selected test devices and their evaluated parameters

Tabulation of results:

Whilst signal overlap (degree of overlap in % of total time) is the decisive factor in terms of the problems facing the searcher, the degree of separation – we call it “Release Level” was chosen as resultant output. This expresses the proportion of the testing period for which the signal was “separate”, i.e. receivable without ambiguity or disturbance. All possible combinations were tested together and the averages of three test runs entered into the table of results (Table 3).

	Arva	Barryvox	Pieps DSP	Tracker DTS	Pieps 457	Ortovox X1	Ortovox F1	Ortovox M2
Arva	*68,15*	*73,62*	*72,17*	*71,90*	*74,40*	*61,25*	*41,93*	*62,50*
Barryvox	*73,62*	*77,34*	*69,77*	*64,44*	*70,49*	*58,10*	*45,58*	*56,97*
Pieps DSP	*72,17*	*69,77*	*66,64*	*63,88*	*70,93*	*54,98*	*41,68*	*58,47*
Tracker DTS	*71,90*	*64,44*	*63,88*	*72,41*	*69,03*	*56,90*	*30,88*	*62,87*
Pieps 457	*74,40*	*70,49*	*70,93*	*69,03*	*69,84*	*57,07*	*41,79*	*62,81*
Ortovox X1	*61,25*	*58,10*	*54,98*	*56,90*	*57,07*	*47,37*	*22,25*	*59,10*
Ortovox F1	*41,93*	*45,58*	*41,68*	*30,88*	*41,79*	*22,25*	*35,60*	*21,84*
Ortovox M2	*62,50*	*56,97*	*58,47*	*62,87*	*62,81*	*59,10*	*21,84*	*47,03*

Table 3: table of results: Release level [%] of total time as mean of 3 ten minute test runs each

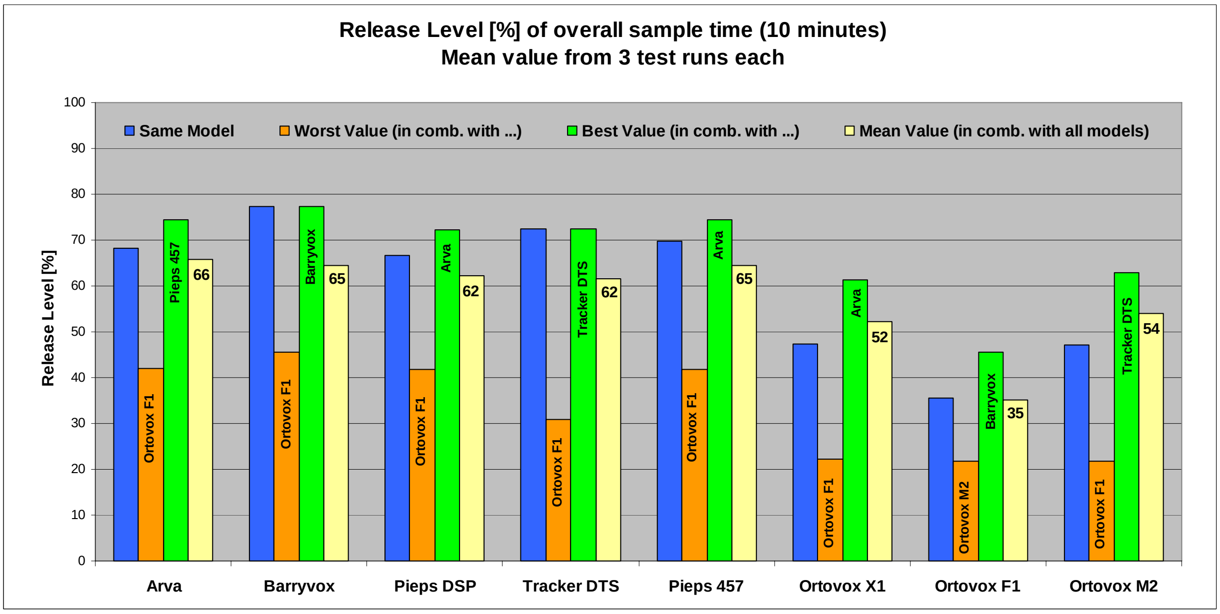

Chart 1: Release level (% of time during which the signals can be received freely and clearly) for pairs of avalanche transceivers of the same type (blue), worst and best results (orange and green), along with the mean of all possible combinations

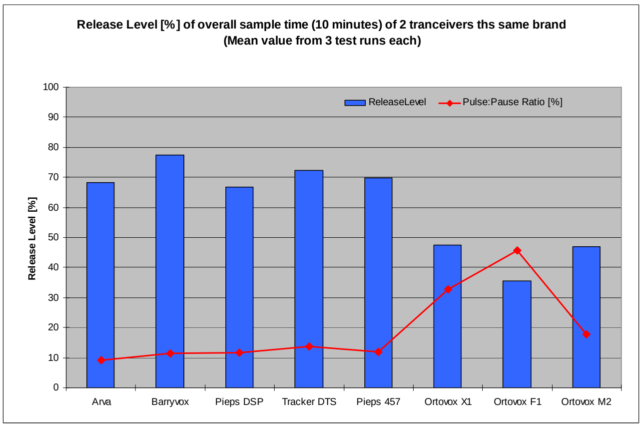

Chart 2: Release Level (% of time during which the signals can be received freely and clearly) for pairs of avalanche transceivers of the same type

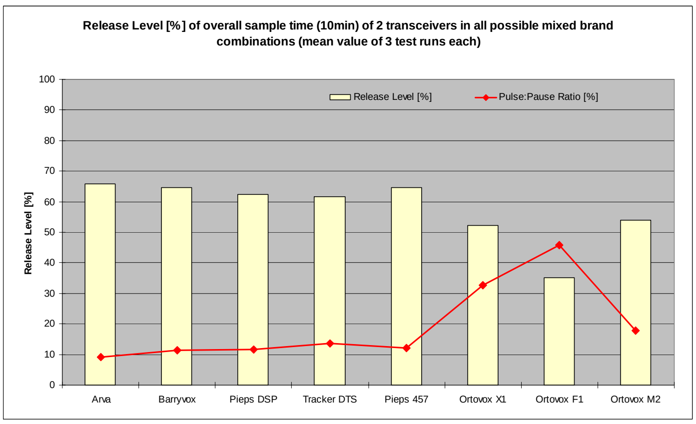

Chart 3: Release level (% of time during which the signals can be received freely and clearly) for all possible device combinations (pairs of avalanche transceivers)

Interpretation of results:

Every manufacturer is fundamentally free to choose the form in which his signal is transmitted, so long as they remain within the boundaries prescribed by the standard. From the results we can recognise several basic strategies used by the various manufacturers and having a decisive influence on the degree of overlap and therefore separation. Ultimately the most influential factor is the pulse/pause ratio.

<u>*Strategy 1: very short pulses with repetition period as constant and long as possible*</u>

A good impulse/pause ratio results in purely mathematical terms in short impulses and a longer period duration – also bringing a positive result thanks to a higher signal release level. In the case of a combination of two devices with almost equal repetition periods, there are long phases without overlap but also correspondingly long phases with interference.

<u>*Strategy 2: short pulses with repetition period as variable and long as possible*</u>

This strategy seems to be standard among modern digital devices. Whether as a result of production variation or through a random number generator activated during switch-on, a different repetition period is defined. This has the disadvantage that overlap occurs frequently, but the decisive advantage that these overlaps are always just brief.

<u>*Strategy 3: short repetition period*</u>

This worsens the pulse/pause ratio and can be expected to cause a higher degree of overlap, but at least it carries the advantage that a more rapid indication is possible on search devices.

<u>*Strategy 4: long pulses, long repetition period*</u>

This strategy was obviously selected without considering multiple burials. Whilst there may be advantages in terms of range, there are significant disadvantages, not least as a result of the unfavourable pulse/pause ratio.

Summary:

In the past it was held that:

> ***Whether an old analogue device or a modern digital device, they all transmit just the same.***

This assertion can be **clearly disproven** by this study. For someone who is buried, what ultimately counts is **how their device transmits** – with the **correct frequency** and the **correct strategy**. If their signal can be detected by the searcher without ambiguity or disturbance, this has a decisive influence on the ease and thus speed with which they can be found, **independently** of the **search equipment** with which the rescuers are equipped.

A short theoretical consideration

Assume that the lenghts T_1 and T_2 of the periods $(1000 \pm 300\,\text{ms})$ of two senders and the lengths P_1 and P_2 of their pulses (≥ 70 ms) are positive natural numbers with

$$T_1 \leq T_2,\ P_1 < T_1 - q,\ P_2 < T_1 - q,\ P_1 + P_2 < T_1,$$

where $q := \text{gcd}(T_1, T_2)$ is the greatest common divisor of T_1 and T_2.

After $K := \frac{T_1 \cdot T_2}{q}$ units of time every sender will be back in the same position. Note that K is the least common multiple (lcm) of T_1 and T_2.

To simplify the formulas we assume that both senders start at the same time with a pulse. This is of course a situation which in practice almost never happens. Assume there is a time delay at the beginning, say of $k \cdot q + s$ time units, k and s natural numbers with $0 \leq s < q$. If $s = 0$, then within $K - T_1$ units of time there will be a moment where both senders start a pulse. If $0 < s < q$, then the values for A differ from the values given below at most by ± 2. The assumption of a common starting point is therefore not a real restriction in the framework of this study.

Let P and Q denote the minimum resp. the maximum of P_1 and P_2 and

$$r := [\frac{P}{q}],\ R := [\frac{Q}{q}],$$

where $[a]$ stands for the greatest integer which is less or equal to a (e.g. $[3,7145] = 3$).

Let A denote the number of time intervals of length ≥ 0 in which both senders are simultaneously transmitting a pulse. A short calculation leads to the following result:

$A = 1 + r + R$, if q divides neither P_1 nor P_2,

$A = 2 + r + R$, if q divides exactly one of the numbers P_1 and P_2,

$A = 3 + r + R$, if q divides P_1 and P_2.

The amount of time U within a cycle of lenght K where the pulses of both senders are completely separated from each other can be calculated as
$U = K - (T_1 \cdot A)$.

Here are some examples:

Example 1
Arva Advanced 1D-0052-1109, T1=916ms and P1=74ms,
Barryvox Opto M0122375, T2=996ms and P2=102ms

We get $q = \text{gcd}(916, 996) = 4$, $K = \text{lcm}(916, 996) = 228084\,\text{ms}$ (3,8 min), $r = [P/q] = 18$ and $R = [Q/q] = 25$. Since Q divides neither P_1 nor P_2, we get $A = 44$. It means that 44 pulses of the two senders overlap. The time where the pulses are separated can be calculated as $U = K - (T_1 \cdot A) = 187780$. The release level F (in percentage) is given by the quotient $\frac{U}{K}$. We get $\frac{U}{K} = 0,82$. In other words: The release level is $F = 82\,\%$.

Other examples:
Tracker DTS 52279, T1=972ms and P1=94ms and Tracker DTS 98618, T2=804ms and P2=96ms ➔ Release Level F=74%
Tracker DTS 52279, T1=972ms and P1=94ms, Ortovox F1 443745, T2=1210ms and P2=370ms ➔ Release Level F=61%
Ortovox F1 821072, T1=1180ms and P1=366ms, Ortovox F1 443745, T2=1210ms and P2=370ms ➔ Release Level F=38%

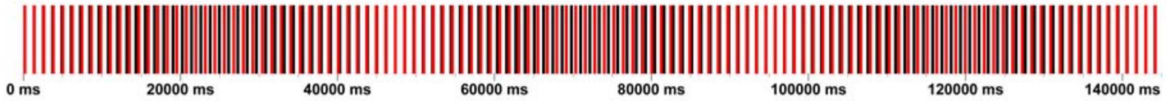

Figure 5: Bar chart of the last example with a least common multiple (lcm) of 142.780 ms (2,4 min) and a release level of 38%. The red and black bars represent two different transceivers. The period length and pulse lengths are shown downscaled.

Also these calculated examples approve, that long period lengths T and – what's more worse – high pulse lengths P are really bad preconditions to solve multiple burial scenarios!

Future:

Completely new avenues are again being followed by PIEPS and a revolutionary new transmission strategy is being introduced.

An update will in future also allow “smart“ transmission. The device also receives and analyses during transmission activity by a neighbouring transmitter. The device’s own signal will then be adjusted and shifted in such a way that there are no more overlaps, independently of the type of neighbouring device involved.
This gives the buried victim the advantage that, in the event of burial close to another victim, their transmitted signal can be received “cleanly” and independently of the source of manufacture of the second transmitter.

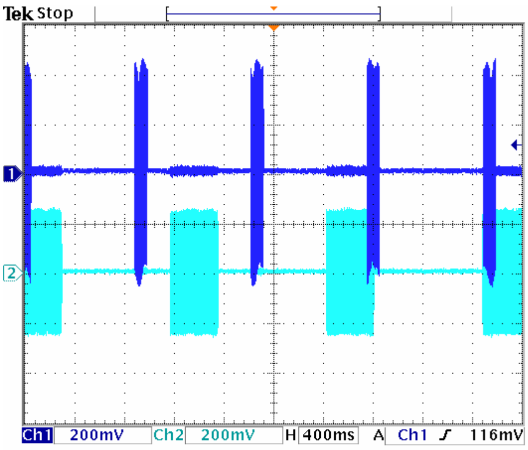

Figure 6: signal A with IS function recognises signal B (light blue) as neighbouring transmitter, initially still with overlap.

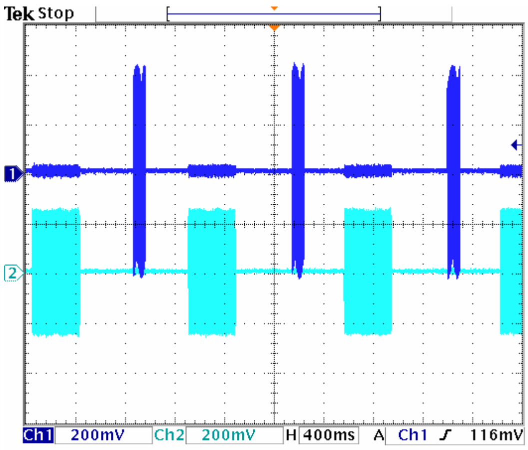

Figure 7: signal A with IS function has adjusted its transmitted signal and shifted it in such a way that no further overlapping with signal B (light blue) is possible.

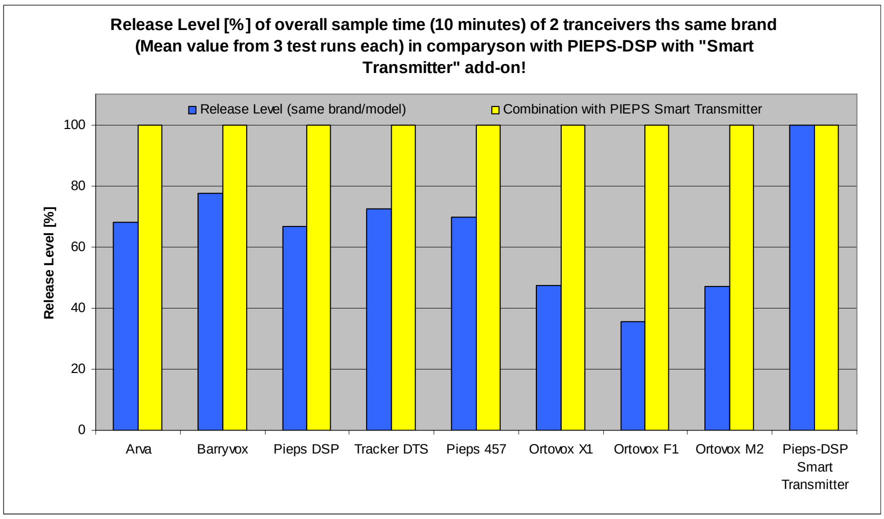

Figure 3:
Release level (% of time during which the signals can be received freely and clearly) for different combinations of PIEPS-DSP with IS option (two avalanche transceivers in each case) in comparison with the values in Figure 1.