About Lost Beeps

September 2011

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On request of the Alpine Committee, Section Moléson of the Swiss Alpine Club SAC

Introduction

In a recent bulletin of my local section of the SAC, some concern was expressed that older analog avalanche beacons may not be detected by newer devices. The alert was given, based on a retrieved article [2] published by ANENA. As a recreation ski tourer for many years, I know that the mountains cannot be experienced without a residual risk. But prematurely redeeming my ticket to heaven, before seeing my first grandchild, seemed too high a price to pay for some lost beeps.
As a retired Electrical Engineer, leading ski tours for seniors, I accepted the suggestion of the Alpine Committee of my local SAC Section to take a closer look at the issue of downward compatibility of avalanche beacons. My contribution has to be understood as a commented abstract made by a committed user - based on publications and some surveys with experts.
I want to acknowledge the encouragement and help that I received, from Felix Meier, Marcel Würgler, Daniel Forrer, Erwin Meister and Jeffrey Heil.

Transmit Frequency and Receiver Bandwidth

Transmit frequency

Most active backcountry skiers of our, and possibly of other Sections of the SAC are equipped with multi-antenna transceivers. But for different reasons some members still use analog single-antenna beacons, most of them are Barryvox VS 68 or VS 2000. Other members (like me) have replaced their VS 68 / VS 2000 but still use their older device occasionally as a backup.

Fig. 1 The author's "beacon fleet"

The communication [1] explains that it may occur that a modern three-antenna device does not detect the presence of an old analog device. The reason is that the receiver frequency tolerance of the new devices has been reduced. Therefore signals transmitted by an old beacon are received by other old beacons but remain undetected by a new device.
These concerns were expressed based on a 2008 ANENA report [2].

Further the communication suggests checking older devices by testing them with a three-antenna beacon at a distance of at least 50m.

These concerns led me to investigate the technical experiences made, regarding the transmit frequency tolerance during the life cycle of the stated beacons. As a start, I had my beacons tested:

Barryvox type	**Tx frequency**	**Δf_{nom}**
VS 68	456.997 kHz	3 Hz
VS 2000	456.998 kHz	2 Hz
Opto 3000	456.995 kHz	5 Hz
Pulse 3.0 *	456.974 kHz	1 Hz

Fig. 2 Transmitter frequencies measured on March 18th, 2011 at Adaxys Labs, Hombrechtikon

*) the nominal transmit frequency for the Barryvox Pulse is 456.975 kHz.

Girsberger Mountain Rescue Technology [10], the manufacturer of these avalanche transceivers which are equipped with quartz crystal oscillators, is testing several hundred VS 68 and VS 2000 every year.
Girsberger certifies that most of the measured transmitter frequencies are within a tolerance of +/- 3Hz and practically all are within +/- 20Hz.

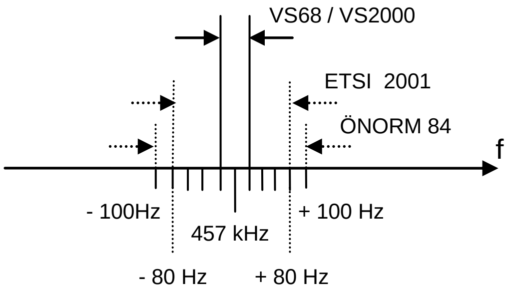

Fig. 3 Frequency tolerance VS 68 / VS 2000

With regard to this data, there is no evidence that the aged VS 68 / VS 2000 have any problem meeting the requirement of the relevant ETSI EN 300 718-1 V1.2.1 (2001-05) [8], stating that the frequency error shall not exceed 80 Hz at 457 kHz.

In fact, the frequency tolerance of a transmitter is determined by the quality of the resonator used by the oscillator. AT-cut quartz crystals are proven to be reliable in respecting the specifications of frequency tolerance. They are much less susceptible to frequency drift due to aging, cold temperatures and abuse-factors than ceramic resonators [4], [5].

The issue of transmitter frequency offset exists but is not limited to analog transceivers; it also occurs with digital transceivers.

The ANENA test report 2001 by François Sivardière [3] gives more precise indications than just mentioning “old analog beacons”. One of the two devices mentioned as transmitting out of the specified frequency tolerance is digital (Ortovox M1) the other (Ortovox F1) is analog. The tested devices were new.

In 2004 another test by Bruce Edgerly and John Hereford [4] was made for a sample of 10 Ortovox F1 transceivers. The results shows a variation in transmit frequency from - 90Hz to + 423Hz.

The report ANENA 2008 [2] does not mention any type of devices, but a query reveals that the problems reported were based on aged, non-serviced Ortovox F1 transmitters faced by digital receivers.

A comparative beacon test published by Pieps [9] shows significant frequency deviations for the Ortovox F1 and M1 compared to other tested devices.

Conclusions:

- *There is no evidence for concern about frequency deviations of V S68 / VS 2000 transceivers to the extent described by the ANENA 2008 report.*
- *In order to avoid problems due to frequency deviation of transmitters, particular attention should be paid to devices equipped with low cost resonators (ceramic resonators).*
- *Current DSP-based transceivers (like Mammut Pulse, Firmware 3.0) verify during group test the frequency deviation (+/- 80Hz). This allows easily identification of possible out of band transmitting devices.*
- *Users should be encouraged to have their beacons checked and replaced if necessary.*
- *The number of antennas of a transceiver does not impact the accuracy of the main oscillator. The myth that all single antenna receivers should be replaced because they do not transmit within the frequency tolerance of ETSI EN 300718 must be discarded.*

Receiver Bandwidth

The current ETSI Standard specifies the transmitter frequency tolerance but gives no explicit value for the receiver bandwidth.

A receiver's sensitivity depends to a large extent on what is termed the signal to noise ratio (S/N), which in turn is inversely proportional to the receiver bandwidth:

$$\frac{S}{N} \sim \frac{1}{B}$$

The processing unit of a digital transceiver requires a higher S/N ratio than an analog beacon. In order to maintain comparable range performance like analog beacons, the receivers in digital transceivers tend to narrow their bandwidth.

Crystal filters

Crystal filters have been in use for more than 30 years in some one-antenna and two-antenna receivers Crystal filters are an attractive approach because of their accuracy and stability. They are also passive devices, which helps in minimizing power consumption.

The bell-shaped frequency response curve of crystal filters allows a gradual transition from the transmission frequency range (Bandwidth) to the frequency blocking range. Therefore signals from transmitters with a frequency shifted into the transition zone are attenuated but not blocked. The report [4] by Bruce Edgerly & John Hereford shows how far out of band transmitting devices are handled by receivers with bell-shaped filters. Even receivers with narrower bandwidth are still able, with reduced range performance to detect non-compliant transmitters.

The report [4] shows a series of measured filter frequency response curves.

Currently, there are no known transceivers on the market with filters that attenuate more than about -9 dB at +/-80 Hz. This translates into a loss in range of about -3 dB or -30%. Considering that most beacons transmit within +/-30Hz, this seems to be well acceptable.

Barryvox VS 68, VS 2000 and Opto 3000 use a crystal filter with a bandwidth (-3dB) of 40 Hz.

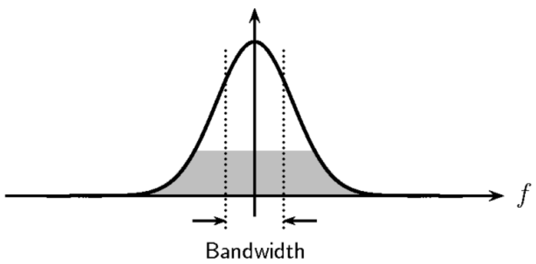

Fig 4 Bell-shaped filter frequency response curve

Bandwidth vs. frequency compliance

To ensure downward compatibility the authors of [4] recommend measures to improve and maintain better transmission frequency compliance. In addition they suggest considering transceivers with wide receiver bandwidth.

In contrast Felix Meier in his contribution [5] is in favour of maintaining the currently used bandwidth. The higher the S/N ratio is, the better the performance of the receiver. Increasing the receiver bandwidth lowers the S/N ratio. Therefore the receiver bandwidth should not be extended because this would mean standardizing on inferior performance. Felix Meier [5] says:

> "Excessive frequency-offset or drift for transmitter oscillators can be controlled through careful design and production. Crystal aging is almost negligible, and the sensitivity to shock can be reduced by proper mechanical design."

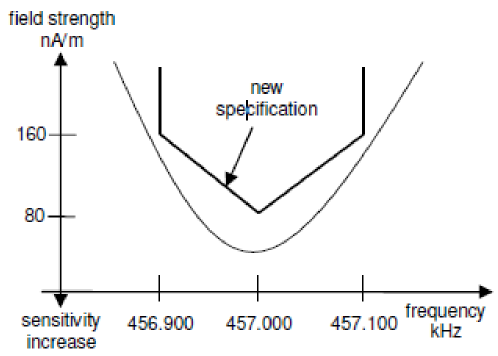

Fig. 5 Proposal for a receiver BW specification [5]

The proposal of Felix Meier is to specify a receiver sensitivity of + 6dB at an offset of +/- 100Hz relative to the minimum sensitivity at 457.000 kHz to produce a noticeable signal. This allows for continued use of crystal filters without incurring a serious penalty (maximum -21% in range).

Advanced Receiver Techniques

Recent receivers use Digital Signal Processing (DSP) to perform advanced filter function. The following indications are taken as an example from Barryvox Pulse.

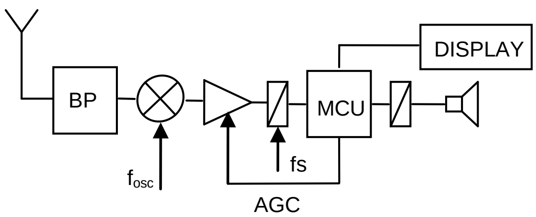

Fig. 6 Simplified Receiver Block Diagram

Fig. 6 shows a simplified block diagram. The antenna signal is first filtered by an analog band pass filter. According to the Direct

Conversion Receiver (DCR) principle, the 457 kHz signal is then mixed down to the base-band. This means that unlike the superheterodyne, the frequency of the local oscillator is not offset from, but right at the received signal's frequency. After A/D conversion an ARM 32-bit microprocessor performs base band signal processing.

A Fast Fourier Transform (FFT) scans the frequency band of 457 kHz, +/- 180 Hz. The FFT allows detecting and locating transmitters with its signal strength on the frequency axis.

Based on the results of the FFT, an algorithm then controls the center frequency and the bandwidth of an adaptive digital filter. Technically the filter stays at base band but the local oscillator is pulled to the filter's center frequency.

The control of the filter is performed by a well-thought-out algorithm taking in account several parameters.

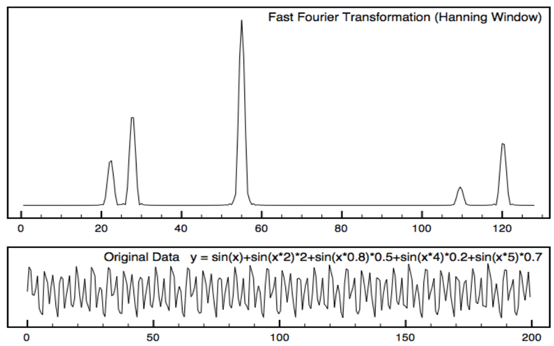

Fig. 7 Fast Fourier Transform FFT

The analog tone is obtained by up-conversion of the base band signal to the audio frequency.

The Automatic Gain Control AGC adapts the amplifier gain according to the signal strength. AGC replaces the rotary attenuation switch of former analog beacons.

Fig. 7 shows an example of an FFT, below the time domain signal generated by several sources and above the corresponding frequency domain as a result of the FFT. Each detected peak corresponds to a transmitter signal and indicates its frequency (horizontal scale) and signal strength (vertical scale).

The filter frequency response curve of frequently used digital filters is characterized as

$$F = \sin\left|\frac{\sin(f)}{f}\right|$$

Unlike a quartz filter with bell shaped curve, a digital filter shows steeper filter edges and it has zeroes outside the filter bandwidth. Therefore transmitters with large frequency offset may be more attenuated or even not detected by digital filters than they would be by analog quartz filters.

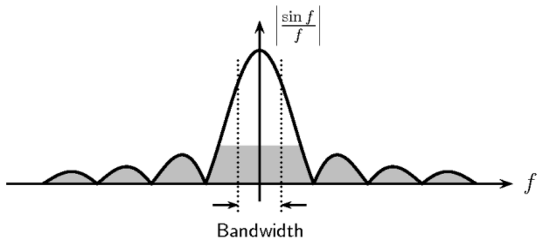

Fig. 8 Digital filter curve

The ability to detect strong, frequency shifted signals and simultaneously weak, compliant signals may be a challenge to adaptive filters. Functional field tests by the author for different multiple burial configurations show that such situations are handled quite well by updated Barryvox Pulse Firmware 3.0.

Conclusion:

- *The ability of a receiver to detect a signal with a frequency offset from 457.000 kHz depends on the type of filter used and, in some cases; the type of digital signal processing that has been implemented.*
- *Indications that recent receivers with narrow bandwidth do not detect compliant transmitters could not be confirmed as far as it concerns Barryvox Pulse Firmware 3.0.*
- *Filter characteristics of DSP receivers may be controlled by firmware; using available updates may optimize receiver performance.*

Multiple Burials

Colleagues from my SAC section may become insecure reading in [1] that: "Analog devices may disturb the searching process of modern three antenna beacons in cases of multi burial situations." What does "disturb" mean? Why do life saving-devices disturb the rescue process rather than support it? Since Multiple Burials seems to be a current topic, a broader look is provided on this issue.

Multiple Burial Situations

In 2002 Manuel Genswein and Stephan Harvey presented a report [11] with a statistical analysis of avalanche incidents. The analysis is based on 466 skier triggered avalanches in Switzerland causing 698 completely buried victims, meaning they had to be located with a transceiver. The analysis concludes:

- *61% of all backcountry skiers who could not be found by visible parts were involved in a multiple burial situation.*

- *If a backcountry skier claims to be able to find 90% of all victims, still leaving out every tenth - then he must be able to solve a six burial scenario.*

- *If he is not able to solve a four burial scenario, he would not have found 25% of all victims.*

A certain share of multi burials can be resolved as a series of single burials. But in cases where buried transmitters are close, the searching transceiver will receive multiple signals from different transmitters. These cases will require a more sophisticated approach.

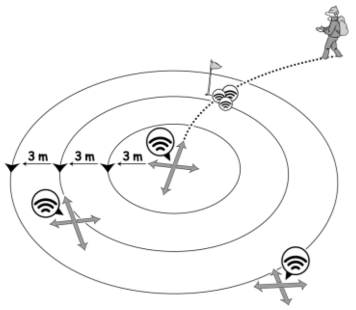

Fig. 9 The Three Circle Method as an example for a formalized method [20]

Experts seem to agree: Those who want to be able to solve any Multiple Burial Scenario with four or more victims needs to master one of the well known formalized methods

- *The Micro Search Strip Method [11] or*
- *The Three Circle Method [16], [20]*

Both methods are systematic search procedures that can be applied in any situation and independently of a specific transceiver technology.

What transceiver does it require?

As mentioned above, both formalized methods do not need a specific transceiver technology.

But to get a thorough analysis of the burial situation, Manuel Genswein [11] emphasizes the advantage of using analog tones. The analog mode answers simultaneously and at all times offering raw data on the question "How many victims are there within which radius?"

However, advantage should be taken of the direction and distance indicated by digital beacons. Digital / analog devices fulfil both requirements.

Chris Semmel and Florian Hellberg, Deutscher Alpenverein DAV, show a comparative test of actual transceivers [19].

Marking functions

Some recent avalanche transceivers offer more extended specific multi burial features including marking function.
The description below is given at user level and applies to the Barryvox Pulse. A more technical approach will be presented on the next paragraph on Signal Separation.

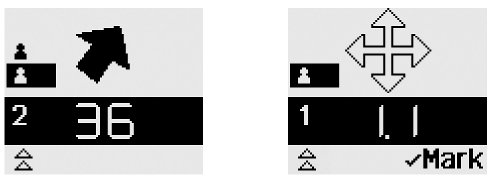

Fig. 10 Multiple Burial Display
In search mode, the transceiver attempts to analyze all the detectable signals and determines the number of buried victims. The victims are then listed according to their distance (signal strength).

The device pre-selects the closest transmitter and leads the searcher to it. Once a victim is located, the searcher will mark the victim on the list. The beacon will then lead the searcher to the next victim. The searcher may - by selecting another victim - overrule the pre-section made by the beacon.

The benefit of this method is that the searching process may be pursued before the located victim is buried out and his beacon switched off. Even though the marking feature may improve the efficiency of the searching process, it has some limits. The Barrvox Pulse manual says:

> "The larger the number of buried subjects is the more difficult and time-consuming the exact analysis of the situation gets, because of overlapping signals. The more signals there are, the longer the signal overlaps can last. The capability to automatically detect and isolate signals from multiple buried subjects is therefore limited."

As a fall back method the device offers the "Analog Mode". The searching process may then be performed as a series of single burials. In case of multiple burials in close proximity, one of the formalized methods mentioned above may be used.

Avalanche transceivers and Multiple Burial are a controversial issue.
Limiting aspects of multi burial features are discussed by Thomas Lund in [12]. This issue will be treated in the next paragraph.

Craig Dostie in [13] entitles "Gadget Fever" and asks "Do we rely on features to avoid practice?"

Another study [23] by Dieter Stopper and Jon Mullen based on the analysis of avalanche incidents in Tirol from winter 97/98 to 02/03 concludes that multiple burial situations that need special searching methods or searching technology are extremely rare. But Manuel Genswein in [14] answers back vigorously by saying that Stopper's statistical sample is by far too small. Furthermore, the fact that the perspective of Stopper's study is set to the "event/avalanche" and not to the "buried/victim" does hide the extent of the problem of multiple burial accidents. Genswein concludes:

> "Although these functions are not capable of solving all problems, they are capable of solving the majority of all victims involved in a multiple burial situation (two to three buried subjects)."

Conclusions:

- *For advanced users, mastering the formalized methods and specific multi-burial features of current transceivers is essential.*
- *Concerns about multi-burial situations should lead to specific education programs for advanced users.*

Signal Separation

In cases of multi burial situations there is a high probability that the searching transceiver will receive signals from multiple transceivers simultaneously. Signal separation isolates the signal of each transmitting beacon in order to be able to locate it. Several strategies are described below.

Signal Strength Analysis

Traditionally, most digital beacons use signal strength analysis to support the search process in case of multi burial situations. This strategy takes advantage of the fact that signal strength decreases with the cube of the distance and therefore helps to isolate the closer beacon.

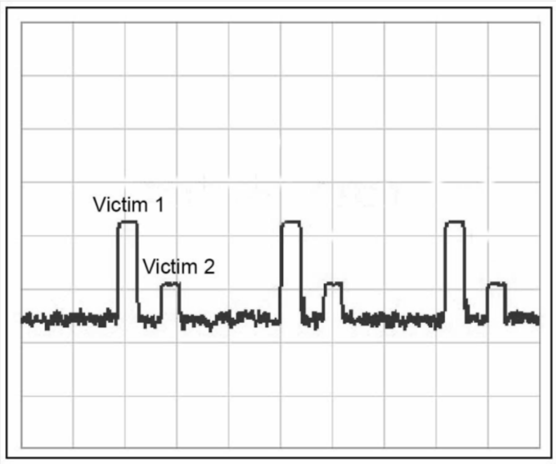

Fig. 11 Signals no overlapping [12]

Using analog beacons or switching to the analog mode of a digital beacon, the searcher uses his sensitivity control to identify the closest transmitter.

Using a digital beacon, the device analyzes the relative amplitude of each signal and leads the searcher to the strongest signal first, by displaying the distance and direction. Further the device may indicate the multiple burial situations by a symbol and reproduce automatically analog tones to assist the searcher in separating the various transmitters acoustically. This corresponds e.g. to the standard mode of Barryvox Opto 3000, and to the so called “Analog Mode” of Barryvox Pulse.

Signal Timing Analysis and Overlapping

In recent years signal-timing analysis has been used to supplement or replace signal strength analysis as a method for isolating signals in multiple burials.

The device identifies each transmitter by the position of its signal pulse edges on time axis.

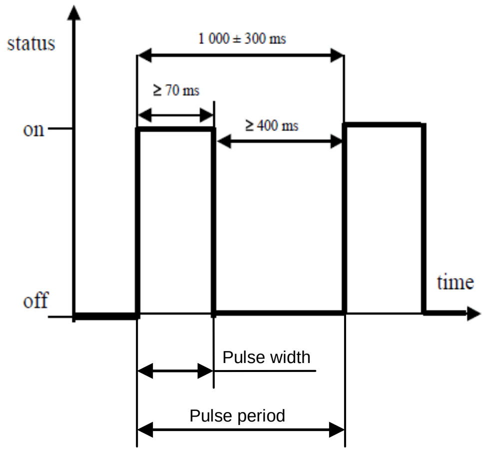

Fig. 12 ETSI A1A carrier keying specification [8]

ETSI EN 300 15 718 specifies the carrier keying (pulse width and pulse period). The given parameter values of this specification allows the manufacturers to determine the length of the pulse width and pulse period in a wide range.

Barryvox type	Pulse width	Pulse period
VS 68	360 – 400 ms	1000 – 1020 ms
VS 2000	320 ms	980 ms
VS 2000 Pro	100 ms	760 ms
Opto 3000	100 ms	950 – 1050 ms
Pulse	80 ms	1060 – 1160 ms

Fig. 13 Examples of pulse width and pulse period

Fig. 13 shows the pulse time parameters for Barryvox beacons. The older, audio-based VS 68 and VS 2000 tend to larger pulse-widths. The pulse periods for Opto 3000 and Pulse are randomized within a given range in 10 ms steps. The randomization occurs for each device during manufacturing according to the last digit of its serial number.

Signals transmitted by different beacons are not synchronized and there is no standardized collision detection mechanism. Therefore in a multiple burial situation transmitter signals tend to overlap periodically.

Overlapping pulses may cause two effects:

- When covered by one or more pulses, the detection of a pulse edge may be impeded.
- In the particular case where two or more signals with nearly identical pulse period are synchronising up, the separation of the edges and their correct attribution to listed victims may become difficult.

Thomas Lund presents a study [12] based on computer modelling and field trials. The study explains that the number N_c of consecutive overlaps is given by

$$Nc = \frac{W_2 + W_1}{|P_2 - P_1|}$$

where W_x pulse width
P_x pulse period

Digital devices often use short pulses to minimize ($W_2 + W_1$) and some have longer periods that vary from device to device in order to maximize abs ($P_2 - P_1$). The variation can be defined during production or randomized during the switch-on time. This strategy has the advantage that the number of consecutive overlaps is low but the overlap series become more frequent.

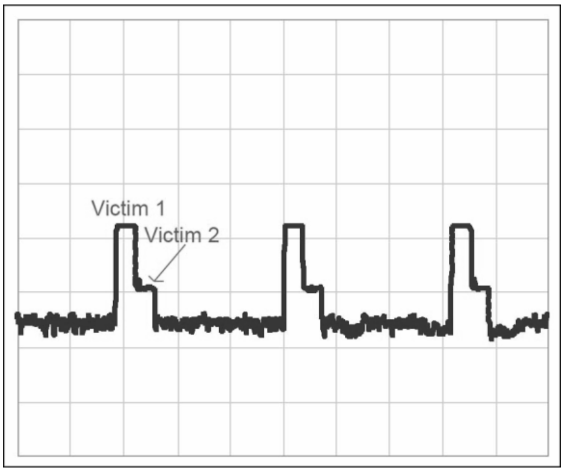

Fig. 14 Overlapping signals [12]

The study [12] reports the probability of obtaining an overlap of specified duration for combinations of two, three and four beacons.

Fig. 15 shows the result for mixed brands of Tracker DTS and Ortovox F1. This combination involves widely varying pulse widths and pulse periods. It is the most favourable situation and leads to the lowest probability for long overlaps.

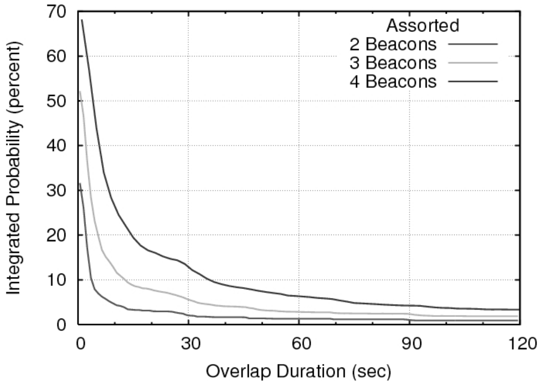

Fig. 15 Probability for overlaps [12]

Similar diagrams for identical brands show significant higher values. For Tracker DTS the probability values are about 3 times as high, for Ortovox F1 about 10 times.

The reason for the higher probability of overlap in the case of Tracker DTS is the limited differences in pulse period among the units.

The case of the Ortovox F1 is similar but has the added complications of very long pulse widths.

Field trials [12] confirmed these results. Signals from even two beacons can remain overlapped for more than five minutes. Moreover information displayed on the searcher's receiver was often inaccurate and confusing when the signals overlap and timing analysis features were engaged.

The report also states that in all cases, switching the unit to basic signal strength mode and employing the Three Circle or Micro Strip method would enable the searcher to locate all of the beacons.

The study concludes that marking functions should be used primarily as a technique to possibly enhance a multiple burial search under ideal conditions. This is mainly limited to cases in which the transmitters are known to have pulse rates with a low probability of signal overlap - transceiver fleets of mixed brands or of the same brands in which the pulse rates have been randomized to minimize overlap.

Receiver Dynamic Range and Blocking

The report [12] says:

> "Marking a particular beacon once located would sometimes take a second beacon out of search."

A beacon has to be marked after having been located with the avalanche pole. Therefore the marking beacon may be held very close to the transmitter.

The searching beacon has to handle simultaneously the signal from the close beacon and signals from distant beacons listed as victims to be located. Since signal strength varies with the cube of distance, the ratio of these signal strengths may exceed the dynamic range of the receiver. This may lead to the temporary loss of a listed victim.

Example:
With a distance ratio of 30 m / 0.5 m, the signal strength ratio is about 107 dB.
This value will exceed the dynamic range of an avalanche beacon receiver.

As an example, for Barryvox Pulse the dynamic range within one AGC-amplification level is > 80dB. The value over all AGC-levels is > 160 dB.

Multiple Burial Algorithms

Felix Meier describes in [15] a method for an algorithm intended for resolving multiple burials with marking feature:

> "At the end of the receiver chain, a suitable method is used for extracting one (or more) features of the received signal that should be used for classifying it. The classification system then enters every new signal feature record into a pool of unassigned records. Every time a new record is added to this pool, the pool is checked for a subset of records that exhibit identical features and can therefore be assigned to a single transmitter. Once such a subset has been found, all records pertaining to it are removed from the pool and are assigned to a chain of records pertaining to a particular transmitter.
>
> When a new record comes in from the feature extractor, it is first checked for matching an existing chain of records. If it does match a pre-existing record set, it is assigned to that chain, and it may also be used for adjusting the feature values. If it does not fit into an existing chain, it goes to the unassigned records pool, and the pool is analyzed again for a possible new chain of signals from a new transmitter."

Separating overlapping signals

The characteristics of two overlapping signals with close frequencies are shown in Fig. 18 and Fig. 19.
S_1 and S_2 represent two transmitted signals and S_o the resulting addition occurring for a receiver in an overlap situation. The frequency f_1 of S_1 is by Δf higher than f_2. The figure shows a relation f_1/f_2 of 7/6. This is more than a real frequency deviation of two transceivers, but it does provide for a simple graphical presentation.

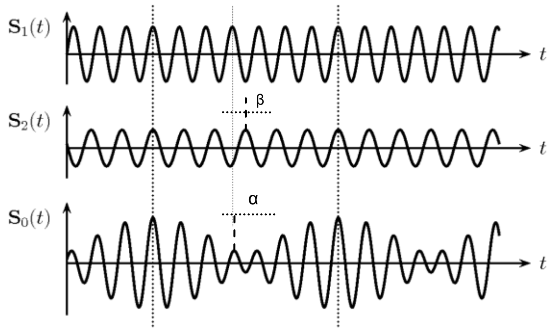

Fig. 16 Overlapping signals on the time axis

Fig. 17 shows the same signals represented by vectors. The length of the vectors corresponds to the signal amplitude (envelope); the angle of the vector represents the phase. Vector S_2 (and therefore the extremity of S_o) rotates with Δf around the extremity of vector S_1.

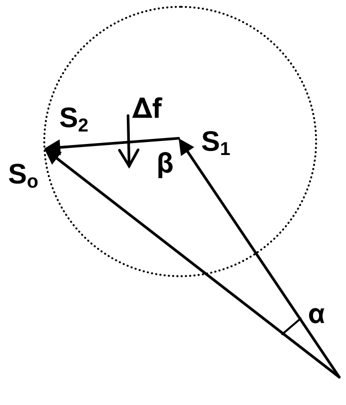

Fig. 17 Overlapping signals as vectors

A signal edge of S_2, overlapped by S_1 may be detected from a receiver by recognizing the jump in amplitude and/or phase from S_1 to S_o.

Implementations show that signal separation during signal overlap is possible. However difficulty increases when more than two signals overlap.

Felix Meier [15] concludes:

> "Contrary to [12], we believe that even in case of signal overlap multiple burial situations can be resolved properly in most of the cases by applying suitable feature extraction and classification algorithms."

Signal Separation and Receiver Bandwidth

Algorithms for signal separation use the rising slope of the signal pulse as time reference to measure the pulse period.

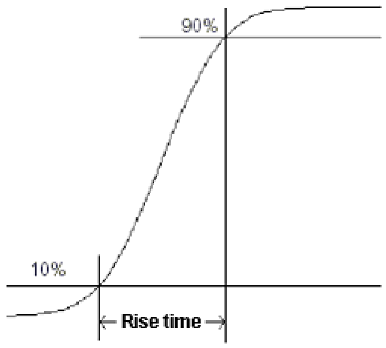

Fig. 18 Rise time

The time required for a signal to change from a specified low value to a specified high value is called rise time t_r. Typical values for low and high are 10% and 90% of the step.

A precise measurement of the pulse period requires a rise time relatively short to the pulse period.

The rise time depends on the bandwidth B. The higher the bandwidth, the steeper is the slope.

$$t_r \sim \frac{1}{B}$$

Rolf Matzner's contribution [18] shows the responses of three filters with different bandwidths to a pulse of 70 ms.

The results show that a filter with a bandwidth of +/- 10 Hz spreads the slope at about half pulse time. In addition the 10 Hz filter oscillates.

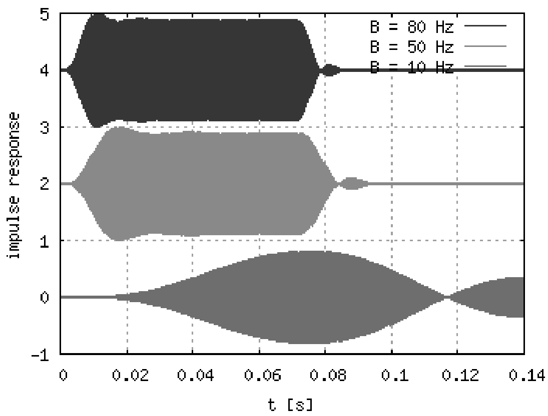

Fig. 19 Response of three filters with different bandwidths B (one-sided) to 70 ms pulse [18]

Conclusion:

- *The choice of a receiver bandwidth is a trade-off between receiver range and precision of the pulse period measurement.*

Wireless-Link (W-Link)

Some transceivers like Barryvox Pulse and ARVA Link use a Wireless Link at 869.8 MHz (Region A, Europe) to enhance signal separation. When in send mode, the transceiver transmits its specific, randomized time signal parameters using a W-Link protocol.

The searching device may use this information to improve signal separation performance.

Carrier frequency analysis

Transceivers may have some individual deviation from the nominal transmission frequency of 457.000 kHz. The deviation of a given transmitter can be used as identification feature. Extracting frequency information from a time domain may be done using Digital Signal Processors for computing the Fast Fourier Transform (FFT) like shown in Fig.9.

According to [15] the boundaries of this approach are given by the resolution of the obtained frequency value. The resolution of the FFT depends from the available (no overlapping) pulse duration. On the other hand the frequency deviation of transmitters is limited too and lies mostly inside a range of +/- 20Hz.

“Smart” Transmitter

Pieps [9] describes their “smart” transmission in [9] as:

> “The device also receives and analyzes during transmission activity by 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.”

However, according to [12] this technique only eliminates signal overlap with two transmitters located within a radius of approximately 5 m. A third transmitter in the vicinity (i.e. the controlled one and two others) makes it impossible to maintain an overlap-free state.

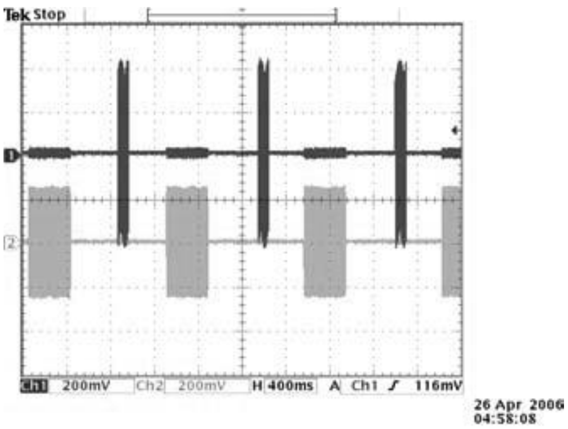

Fig. 20 “Smart” transmission [9]

Furthermore, the shifting pulse rate of “smart” transmitters can disturb the signal time analysis of the searching beacon. A changed pulse rate may be misinterpreted as an additional transmitter [12], [14], [15], [18].

Continuously Running Oscillator

Some beacons have an oscillator which is continuously running when in transmit mode. During pulse pauses the transmitter amplifier is switched off but the oscillator remains still running. Therefore a weak signal may radiate in closer proximity of the transmitter. A sensitive receiver can detect this oscillator signal in a very close proximity to the transmitter. When held in close position to the transmitter and then moved (e.g. during marking), certain receivers (e.g. Barryvox Pulse, Pieps DSP) tend to misinterpret this weak signal as a true signal from a distant beacon. This problem could be avoided by reducing the amplifier gain (Automatic Gain Control AGC). But this measure would decrease the performance to maintain simultaneously the reception of weak signals from distant transmitters.

Conclusions:

- *Marking features based on signal time analysis works quite well in most situations, including in situations with older beacons involved.*
- *Frequent and long overlap situations may limit the efficiency of signal time analysis.*
- *The critical overlap-parameters are pulse width, pulse period similitude between transceivers and pulse period inconstancy.*
- *To solve any multi burial situation, formalized, device-independent searching strategies are essential.*
- *Users of marking features should be taught how to recognize the signs of signal overlap.*
- *The analog mode may be useful to solve multiple burial situations.*
- *Arrangements for searching exercises may possibly be more severe than intended if using mainly transmitters with long pulse width.*
- *There is no perfect solution to solving the multiple burial problems at device level.*

Miscellaneous

Compatibility and Standardization

In several contributions e.g. [4], [5], [12], [15] address the question of an adaptation of the relevant ETSI Standard and a phase-out of non conforming older devices. Avalanche beacons are life saving devices. Downward compatibility with older beacons and interoperability between transceivers of different manufacturers is essential. There is no doubt that several recent improvements are of great interest to the user but some of them are proprietary or not entirely compatible with older devices and therefore limited in their benefit.

The following issues could be taken into account in order to improve compatibility and performance of avalanche beacons:

- Frequency tolerance
- Receiver bandwidth
- Pulse width
- Pulse period
- Pulse period continuity
- Randomizing of pulse period

Furthermore the interoperability of the following features should be improved

- Transmission of time signal parameters over W-Link

The questions of an adaptation of the relevant ETSI Standard and a phase-out of non conforming older devices may be raised if user organisations like SAC advocate for updating standards and encourage manufacturers to conclude agreements in order to improve the interoperability of non standardized features.

The revision of an ETSI Standard is strenuous and time-consuming while technical renewal goes fast.

Some problems like the increased difficulty for signal separation due to long pulse periods are mitigating gradually with replacement of older devices.

Conclusions:

- *An adaptation of the ETSI Standard would be desirable and useful but probably difficult to be realized.*
- *The effects of long pulse width are gradual and diminishing with ongoing replacement.*
- *The limits of multi-burial features should be evaluate by considering the overall avalanche rescue conditions and with common sense.*
- *A general phase-out recommendation to SAC members for older beacons with longer pulse width, without an adaptation of the ETSI Standard looks unnecessary and is therefore not appropriate.*

Multiple Burials and Education

In [22] Manuel Genswein shows how avalanche rescue education programs, including multi-burial situations could be structured.

Maintenance

A service centre [17] is testing systematically transceivers during avalanche courses for professional rescue teams. It reports that about 5 – 10% of the tested devices is defective or has reduced performance. The estimation is based on several hundred tested devices.

The main raisons for the failures are
- damages due to leaking batteries and
- broken antennas

Additional advice regarding maintenance for Barryvox beacons is given in [21].

The recommended service interval is specific to each manufacturer.

Manufacturer	Recommendation
ARVA	3 years
Barryvox	3 years
Pieps DSP	Dispensable, comprehensive self test
Pieps others	3 years
Ortovox	First after 5 years, then 2 years
Tracker	Extended function test by user

Fig. 21 Service recommendations

Conclusion:

- *The recommendation for periodically servicing and updating avalanche transceivers is appropriate.*

Appendix

Fundamentals and features of avalanche beacons

The Decibel

The Decibel, or dB for short, is a logarithmic measure for the ratio of two quantities. In our case, it is defined as

$$n\,dB = 20\log_{10}\left(\frac{H_1}{H_2}\right)$$

If $H_1 = 2 \cdot H_2$, then their ratio in dB is

n = 20·log$_{10}$ (2) = 6 dB,

If $H_1 = 0.5 \cdot H_2$, then their ratio in dB is

n = 20·log$_{10}$ (0.5) = -6 dB

Since dB is a logarithmic measure, taking roots is reduced to division:

The third root of 6 dB is 6/3 = 2 dB.

Properties of 457 kHz frequency for avalanche transceivers

The wavelength λ for a frequency f is given by

$$\lambda = \frac{c}{f}$$

With c: Speed of Light: 3 10^8 m/s

For f = 457 kHz: λ = 656 m

The area within a distance

$$r < \frac{\lambda}{2\pi}$$

from the transmitting antenna is termed the near field. In the near field, the field strength H decreases with r^{-3}.

$$H \sim \frac{1}{r^3}$$

For distances outside the near field, i.e. in the far field, the field strength decreases with r^{-2}.

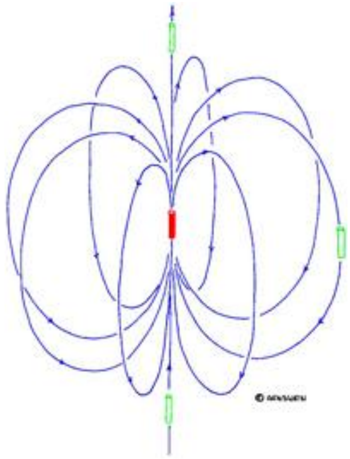

Fig. 1 Field lines in the near field

The avalanche beacons use ferrite antennas to receive the magnetic field H. If the range of an avalanche transceiver is < 100m, it is definitely operating within the near field. This means that the field strength varies very strongly when the receiving beacon is moved relative to the transmitter. This is an advantage for the searcher.

Another advantage is that inversely, the distance indicated by the beacon is not very sensitive to field strength variations. This explains why the distance indicated by the searching beacon is just a little dependent on variations of the transmitting power and also from the state of charge of the battery.

The fact that attenuation is varying strongly with distance helps considerably to separate signals by strength in a multi-burial situation. Another advantage of the long wavelength is that there is very little attenuation due to snow.

A disadvantage of the 457 kHz frequency is that, in its near-field application, the field is curved.

The field strength may be represented by means of field lines. The density of the lines corresponds to the strength of the field. As shown in Fig. 1 the field lines emerge from the antenna at one end and following a curve, re-enter the antenna at its other end.

A searching multi-antenna beacon indicates the direction toward the transmitter by following these field lines. This means that the path to the transmitter follows a curve unless the antennas of the receiver and of the transmitter are aligned on a straight line.

Future developments could lead like those proposed in [7] to add a higher frequency to the 457 kHz carrier. This would increase the detection range and would allow giving each transmitter a unique identifier (ID) so that multiple victims can better be isolated. Since the operating range would be in the far field, a transmitter can be considered to represent a point source; initial detection would point in that direction. The 457 kHz would still be used for fine and pinpoint searching in the near field.

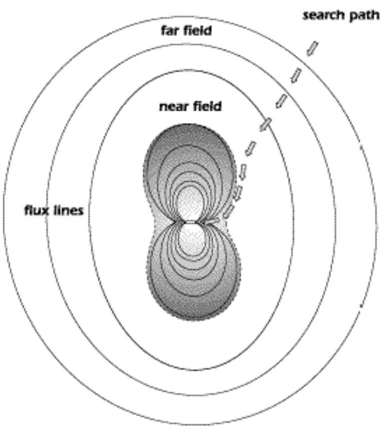

Fig. 2 Near field and far field

Indications for distance and direction

Working in the analog mode, the receiver uses the main antenna signal X.
For the digital mode the signal Y, as received from a second, orthogonal antenna (smaller) is used in conjunction with the signal X.

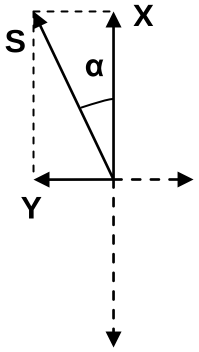

Fig. 3 Distance and Direction

The distance is determined based on the signal intensity

$$S = \sqrt{X^2 + Y^2}$$

The magnitude of the angle is given by

$$\alpha = arctg \frac{|Y|}{|X|}$$

The sign of the angle (clockwise or counter-clockwise) relative to the X antenna axis can be determined by taking into account the phase of the Y-signal relative to the phase of the X-signal.

Basically, both antennas are bidirectional. Therefore, the beacon may show an arrow pointing in the inverse direction. But In that case, the distance indication will be increasing when moving in the arrow direction. The user has to check for this and, if necessary, to move in the opposite direction. Some devices indicate when the direction is opposite.

The third antenna

During searching, captured signal strength depends on the orientation of the receiving antenna with respect to the field of the transmitting beacon. In case of deep burials (> 1m) misleading maximum signal strength may occur with single- or with two antenna devices. Special searching techniques (pinpointing in a circle / line) are needed to solve deep burial situations.

Fig. 3 Three antennas

The third orthogonal antenna allows capturing the field of the transmitting beacon in its spatial dimension and eliminates misleading signal strength.

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Abstract

In the transmit mode all avalanche beacons operate basically equally. Compatibility is assured by the standard ETSI EN 300 718. For some older models not equipped with quartz resonators, the transmit frequency may drift out of tolerance. When using the marking function, new receivers may have increased difficulty to perform signal separation if analog transmitters are involved. Marking functions may be useful in case of multiple burials. But because marking functions do not work reliably in every case their importance should not be overstated. The ability to solve any multiple burial scenarios implies to master one of the well known formalized methods, the micro search strip method or the three circle method. In the search mode, three-antenna devices allow a simpler and faster location than one-antenna devices. It is recommended that 1) group tests be performed using three-antenna devices with frequency test function, 2) devices should be periodically serviced according to the manufacturer recommendations, 3) relevant software updates be installed and 4) three-antenna devices should be considered for new acquisitions.

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