AVALANCHE BEACONS: ENSURING INTEROPERABILITY AND BACKWARD COMPATIBILITY

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ABSTRACT: With detection ranges exceeding 50 meters, and reliable, user-friendly signal isolation of 3 and more transmitters, even located closely to each other, leading-edge beacon technology today scratches physical limits. Well behind these technological frontiers, several less spectacular improvements are being discussed or have already been introduced to the market. Less spectacular, since none of these issues will make such a large difference to the user as true multi-burial support. Technical features and questions investigated are: the proposal to further narrow the bandwidth limits for transmitted signals, the approach to control transmitter pulses adaptively with respect to other transmitters in the immediate neighborhood, and the collection and transmission of a buried person's "vital data". Additional remarks are made regarding widely deployed beacons using a steadily active oscillator and randomization of transmitter pulse parameters. All those more technical details may have a strong impact on (i) future beacons' compatibility with today's models, and (ii) on the interoperability between different vendors. Moreover, even a presumably pure technical feature can influence search and rescue strategies and raise ethic and legal questions. This paper confronts the gain (search strip width, marketing advantages, ...) with the cost in terms of backward compatibility and interoperability issues.

KEYWORDS: Avalanche, beacon, transceiver, compatibility, interoperability

1 COMPATIBILITY AND INTEROPERABILITY

Increasing complexity of electronic devices always tends to hinder a flawless interoperability between devices of different vendors. This is true for widespread technologies such as Bluetooth and WLAN as well as for avalanche beacons. However, while the lack of interoperability between two WLAN devices might force the user to replace one of them by a different model, insufficient interoperability of two avalanche beacons can cause the death of a person buried.

Moreover, technical progress usually requires the user to renew her technical equipment from time to time. This is widely accepted by customers in consumer markets. Avalanche beacons, however, are often seen as a piece of equipment for life. There are hundreds of thousands “old” beacons out in the field. While in a consumer market no longer supporting an old VCR standard will leave behind an unsatisfied customer, the same argument in a safety market like avalanche beacons will leave behind a dead customer.

Obviously, one of the foremost tasks of a standardization body is to define rules with sufficient precision to ensure that all devices by all vendors complying with the standard are fully interoperable. This goal usually can no longer be met once technology moves forward faster than the discussion process in the standardization bodies can follow. This is the case right now. Several technological developments of the last couple of years are either dependent on assumptions not explicitly mentioned in the applicable standards, or influence the search process and behavior of users the standards are to be based on.

In the sequel, we will illuminate several technological developments already introduced into the market or under discussion with respect to their effect on interoperability and compatibility. In the first part, we focus on the signal level in terms of frequency, bandwidth, oscillator signal and impulse timing. the second part deals with the influence of additional data provided by beacons on the search process.

2 FREQUENCY, BANDWIDTH, TIMING

2.1 <u>Receiver Bandwidth</u>

A beacon receiver is able to detect signals in a certain vicinity of the nominal frequency of 457 kHz. Roughly, this vicinity is called receiver bandwidth. Unfortunately, the receiver not only listens for a potential signal within its bandwidth, but also collects noise. The larger the bandwidth, the more noise is collected, which in turn reduces the sensitivity for distant signals. Doubling the bandwidth reduces the range of the receiver by approximately 11 %, halving the bandwidth increases the range by 12 %. Shrinking the bandwidth from ± 80 Hz to ± 50 Hz as proposed by Meier (2006) would increase a beacon's range from e.g. 50 m to

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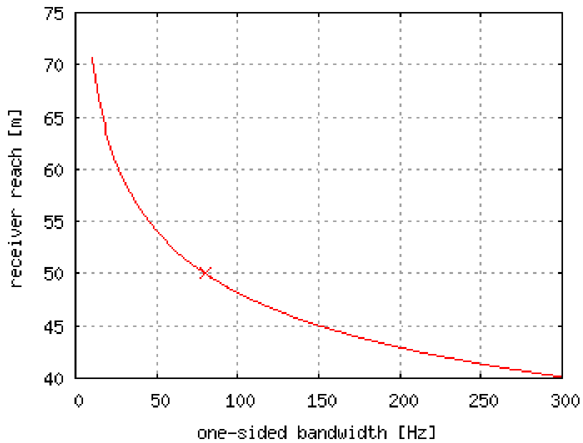

Figure 1: Potential detection range as a function of the receiver bandwidth. The marker (X) indicates the maximum frequency deviation of a transmitter allowed by today's standards.

54 m.

The relation of receiver bandwidth and the receiver's potential detection range is depicted in fig. 1. From this point of view a narrow bandwidth would be highly desirable.

2.2 Timing Detection

Due to a fundamental law in signal theory the precision to measure the begin and the end of a signal impulse increases with the receiver bandwidth.

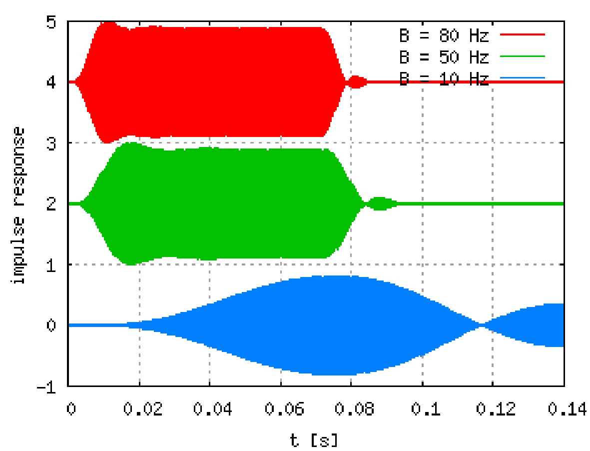

Figure 2: Response of three filters with different bandwidths B (one-sided) to a 70 ms impulse.

Figure 2 shows the response of filters with various bandwidths to an impulse with 70 ms width. While the 80 Hz and 50 Hz filters reproduce start, end and duration of the impulse pretty well, the 10 Hz filter oscillates and spreads the impulse energy over a huge time interval. Comparison of the 80 Hz and the 50 Hz filters shows the much sharper slope of the broader filter. A sharp slope allows a precise timing measurement, which is crucial for signal separation and marking in multi-burial scenarios.

2.3 Noise Characteristics

The dependence of the range on the bandwidth as stated before (fig. 1) holds for white noise only. White noise is an idealized analytical model of a time-invariant noise process with a flat power spectral density. In practical environments, however, white noise is rarely the limiting factor. Important noise sources are electric discharge in the atmosphere (up to thunderstorms), radiation of mobile phones, noise caused by funicular motors etc. This noise is characterized by randomly distributed impulses. In a real narrowband receiver, each of these impulses triggers an oscillation. Such an oscillation lasts the longer, the smaller the receiver bandwidth is. Although in a pure white noise environment a smaller bandwidth gives better performance, this is no longer true when the receiver is exposed to more realistic impulse noise.

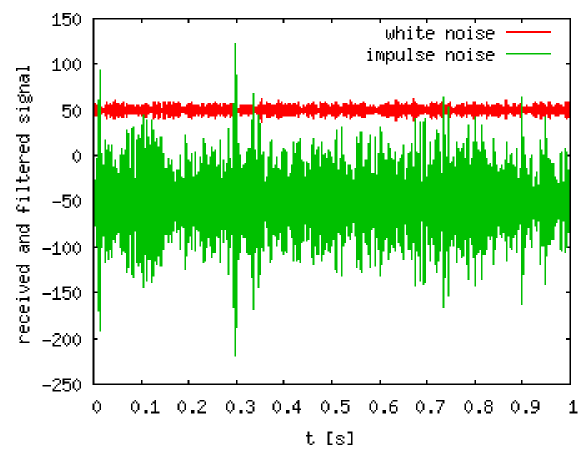

Figure 3: Myth and reality: (Almost) white noise in a clean environment (top) and severe impulse noise in the vicinity (approx. 25 m) of large motors (bottom).

Figure 3 illustrates the difference between white noise in a clean environment and severe impulse noise near the motor station of a funicular in the Arlberg region in Austria. Depicted is the received signal after a frontend filter with approx. 200 Hz bandwidth without any beacon transmitting. The impulse noise clearly masks a 40 m beacon signal.

2.4 Compatibility and Safety Margin

The applicable European standard EN 300 718 for avalanche beacons requires the transmitter frequency to be in an interval of ± 80 Hz off the nominal frequency of 457 kHz. The number of beacons adhering to this standard produced until today will very well reach one million. We have to assume that a considerable share of these beacons – especially the older ones – will show frequency deviations scratching the limits of the standard. Obviously, a modern avalanche beacon must be able to flawlessly detect an older beacon. Legally, this requirement might be softened by adopting the standard. However, hundreds of thousands of “old” beacon owners will consider this a breach of trust.

Another point worth some consideration is aging. Even beacons transmitting near the nominal frequency at the time of sale might show some long-term drift towards the limits of tolerance over the years. Although all manufacturers recommend a regular service, a receiving beacon should not rely thereon. Much more a receiver's bandwidth should have some safety margin for old beacons that lack maintenance.

2.5 Performance – Compatibility Trade-off

“There ain’t no such thing as a free lunch” (Heinlein, 1966). If we want to increase the distance range of the receiver, we need to decrease the bandwidth. If we emphasize correct signal separation and marking in a multi-burial scenario, we cannot go below a minimum bandwidth. If we want to be able to search beacons sold in the past, we cannot decrease today's receiver bandwidth. Eventually, if we want to cope even with old, insufficiently maintained and defective beacons we need to provide a pretty large bandwidth.

We can condense these contradicting goals into two fundamental requirements:

1. All transmitters compliant with the current standard must be received almost equally well.
2. Very old and defective transmitter exist, but are not likely to occur. Given such a transmitter, a decline in receiver performance is acceptable.

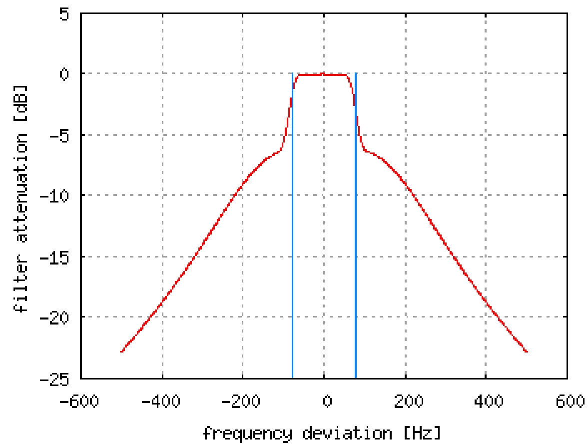

Figure 4: Frequency response of a combined narrow-band and wideband filter.

A possible solution is a filter characteristic combined of a high-gain narrow filter and a low-gain wideband filter, cf. fig. 4.

The narrow filter guarantees a good performance for standards compliant transmitters. The wideband filter ensures that even transmitters with very high frequency deviation (e.g. 300 Hz) can be received, albeit at the cost of a reduced range.

In this example, the wideband filter is adjusted to half the gain (−6 dB) of the narrow-band one. This is enough to reduce the additional noise contribution of the wideband filter significantly. The receiver range is reduced by only 6.8 % (i.e. about 3.5 m) compared to a pure narrow-band receiver. On the other hand, signals around the 80 Hz tolerance band edges can still be detected at almost 80 % of the distance for nominal frequency signals. The filter attenuation increasing with the frequency deviation of a signal resembles the decreasing probability to be confronted with such a transmitter in the case of an accident. But even for a for sure defective transmitter with 300 Hz deviation the range is still larger than 50 % of the nominal range.

While a standard should not enforce certain technological solutions to a given problem, it should clearly state the goal to be achieved. In the case of bandwidth, not only the maximum frequency deviation of the transmitted signal should be defined, but also the capability of receivers to detect signals deviating from the nominal frequency.

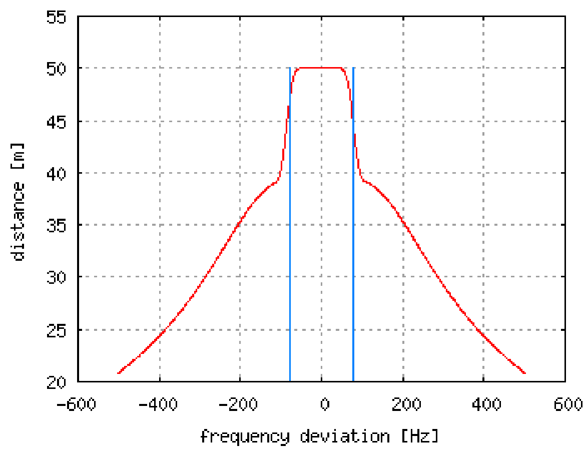

Figure 5: Receiving range of a transmitter dependent on the transmitter's frequency deviation. The range at nominal frequency (457 kHz) is set to 50 m.

To define the limits of compatibility with old and defective beacons is of much greater importance than the question if the deviation limits should be decreased from 80 Hz to some lower value.

2.6 Timing Considerations

The choice of timing parameters (pulse period and duration) has a significant influence on the probability that transmitted signals of two or more beacons overlap and render any measurement of direction and distance unreliable. All beacons manufactured today show pulse widths at the lower end of the interval allowed by the standard, thus minimizing the probability of signal overlap.

Parameter Randomization

A real problem occurs, if the impulses of two transmitters overlap in time and moreover, their respecting pulse periods are identical. Then the overlap state will remain indefinitely. A very appropriate means to avoid such a situation is to use analog, linear components to generate the impulse timing. The natural tolerances and drift of passive components will most probably ensure at least slightly different parameters.

In an all-digital transmitter the natural spread of analog components can be simulated by a random initialization of pulse period and impulse duration. In order to fully achieve the advantage of transmitters controlled by passive components an additional drift can be included, cf. fig. 6. This drift ensures a slow variation of impulse parameters even for the unlikely case that the random initialization gave the identical results for two beacons.

Transmitter Management

Another approach to overcome long states of signal overlap is to control the pulse parameters in accordance to transmitters in the vicinity. The idea is to adjust phase and period of the pulse such that the pulse is transmitted exactly during the off-time of the neighbored transmitter. The most disappointing drawback of this concept is that it only works for two transmitters. A third transmitter in the vicinity (i.e. the controlled one and two others) makes it impossible to maintain an overlap-free state. On the other hand, a situation with only two transmitters in the same area can easily be solved by modern beacons with multi-burial support (Genswein 2008).

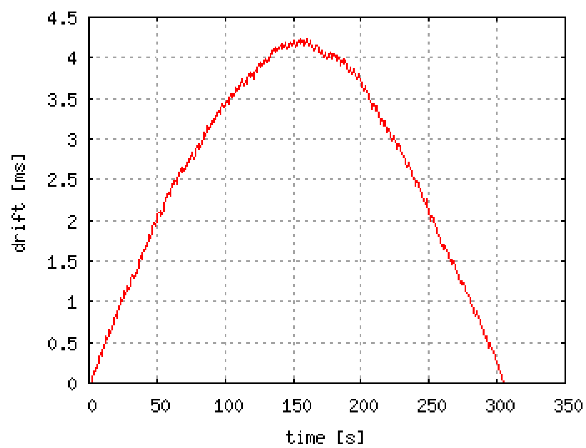

Figure 6: Typical drift of the pulse period for an oscillator controlled by passive components.

From an interoperability point of view there is another interesting aspect of this technology. Adjusting pulse parameters in accordance with the vicinity requires to *change* the pulse period. This can be done smoothly or abruptly. At any rate, a signal with a changing time interval between subsequent pulses is no longer *periodic* in the strict sense, and thus no longer has a well-defined *period*. From a very strict point of view this is a violation of EN 300 718. This is even more dramatic, since modern beacons with signal separation and marking capabilities rely on a well defined period to distinguish different transmitters.

So even a slightly generous interpretation of the standard endangers the interoperability with other beacons. A standard must be treated respectfully. It should not be interpreted generously. Others might rely on the details.

2.7 *Steadily Running Oscillator*

A huge share of the beacons sold during the past decade has a steadily running oscillator. While transmitter amplifier and antenna are switched off during pulse pauses, the oscillator continues to run. A sensitive receiver can detect this oscillator signal in a very close distance to the transmitter. While this behavior is in accordance with the standard, a certain receiver type tends to misinterpret the weak oscillator signal as a true signal of a distant beacon, thus causing some confusion with the searcher.

The analysis of this issue follows the same arguments as with the receiver bandwidth before. Hundreds of thousands beacons sold and operating in the field cannot be ignored. It is the engineers' task to understand this situation as a challenge and to develop a solution compatible with all existing beacons. State-of-the-art beacons prove that the solution is possible and feasible.

Existing beacons using a certain, standard-compliant technology are a fact. New technology should aspire to be compatible with existing technology – even if the standard does not explicitly require this.

3 SO-CALLED VITAL DATA

Two years ago, a beacon was introduced which is able to collect so-called “vital data” of buried persons and transmit this data to the searchers (CSAC 2006). Due to the lack of any standardization this works between beacons of this same type only.

3.1 *Functional Basics*

The “vital data” is derived from minor movements of the chest due to aspiration and/or heart beat. As long as there is some movement, the system detects positive vital data, otherwise no vital data is detected. The results are transmitted to the searcher's beacon using an ISM frequency in the 800 MHz band. The idea is to maximize the expected value of victims recovered alive by sorting them in order of their vital state.

This technology gives rise to several questions concerning the technical reliability, the correctness of the technology applied to the problem of detecting the vital state, and – last but not least – ethical questions.

3.2 *Technical Reliability*

The first question is if one can ensure that heart beat and/or chest movement due to aspiration always cause a positive movement detection by an acceleration sensor. This question can probably be answered with yes, as long as aspiration and heart beat are regularly strong and the beacon is worn according to the manufacturer's instructions. If one of these conditions is no longer true – e.g. the beacon is worn above a thick pullover or got out of its exact position during the accident – the detection may become unreliable.

Another issue is the frequency band used to transmit this information. While the frequency band used shows a fairly low attenuation in dry snow, attenuation becomes arbitrarily high – and the transmission range arbitrarily low – as soon as the ratio of water in the snow increases. This is true for all frequencies above several MHz. The pretty low 457 kHz frequency used in today's beacons was chosen exactly for this reason.

3.3 *Medical Reliability*

A very interesting question is if aspiration and heart beat are well-chosen indicators for the real vital state of a person. At first it has to be stated, that in a number of countries the brain death is the only criterion to indicate a human's death. In other countries cardiac arrest is a sufficient indication, e.g. for organ transplant. However, the debate in this field is very controversial.

Moreover, once the body gets undercooled (hypothermia), all activities in the outer spheres of the body are greatly reduced. In consequence, in the state of hypothermia, aspiration and heart beat may be hard to detect even by medically skilled personnel. On the other hand, due to the fold-back of body functions, such an undercooled victim consumes less oxygen and hence can have an increased chance to survive (e.g. Lafenthaler 2002)!

From a first analysis point of view, the technology chosen seems not to deliver suitable results to rate a buried persons chance to survive.

3.4 *Compatibility*

Since the technology is not part of any standard, only beacons of the same manufacturer X are able to exchange vital data. Let us consider a scenario with four persons buried, two with an X beacon and two with other manufacturers' beacons (O). One of the buried X's be alive, the other one dead. Let us further assume the searcher also to use an X beacon.

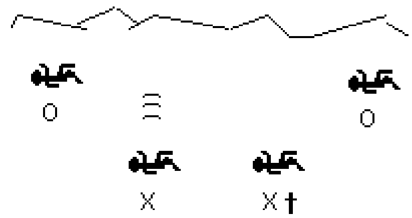

Figure 7: A scenario with four buried, two wearing beacons with vital signal (X), two wearing other beacons (O).

If everything works well, the searcher will receive a vital signal from one buried X, and nothing from the other X and the two buried O's. This clearly does not mean the two buried O's are dead, they simply are wearing the “wrong” beacon. However, a searcher adhering to the “vital function” will start probing and shoveling at the first X with “vital signal”. We observe the following problems:

1. The searcher might ignore the fact that the person with “vital signal” is buried at a much greater depth than the other two with O beacons.
2. The searcher might interpret the lack of a “vital signal” as a “dead signal”.
3. Buried persons with O beacons will be treated the same way as buried persons with X beacons and no vital signal.

In consequence, using X beacons in a mixed environment may urge the searcher to prioritize buried persons wearing X beacons over those wearing O beacons – although there needs not to be an objective reason to do so.

The search process itself is not covered by the standard at all. Providing additional information of unclear reliability, difficult to interpret, influences the search process dependent on the devices involved and may lead to unintended results.

4 CONCLUSION

For safety devices, interoperability between different vendors' models and compatibility with older devices is of much higher importance than in other consumer markets. Although a standard's task is to ensure interoperability, technical progress usually is faster than the adoption of any standard can be. Hence the manufacturers are required to interpret explicit and implicit requirements by the standard conservatively. New developments not only should contribute to a faster and easier search, but also have to be thoroughly investigated regarding their influence on interoperability.

Almost any of today's technical discussions raises interoperability and compatibility questions: The tolerance to be specified for the transmitter frequency cannot be discussed without an analysis of the required receiver bandwidth. This one in turn depends on compatibility requirements with older beacons as well as a safety margin for defective beacons and the requirements imposed by state-of-the-art beacons with signal separation.

Any new technology has to cope with the properties of already existing beacons. It is unrealistic to assume hundreds of thousands of customers renew their equipment just to satisfy technical shortcomings of a new technology.

Even additional data – like vital data – presented by a beacon should be seen carefully. Of course the information must be reliable. It has to be investigated, which conclusions the user draws from the information presented, and if this conclusion helps to save lives.

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