DETERMINING THE WIDTH OF A SEARCH STRIP
FOR AVALANCHE BEACONS

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ABSTRACT: The width of the coarse search strip that is applied when scanning an avalanche is a major factor influencing the time to locate buried victims. Wider search strips help in reducing this time. If the width is chosen too large, there is some risk of not detecting a buried person.

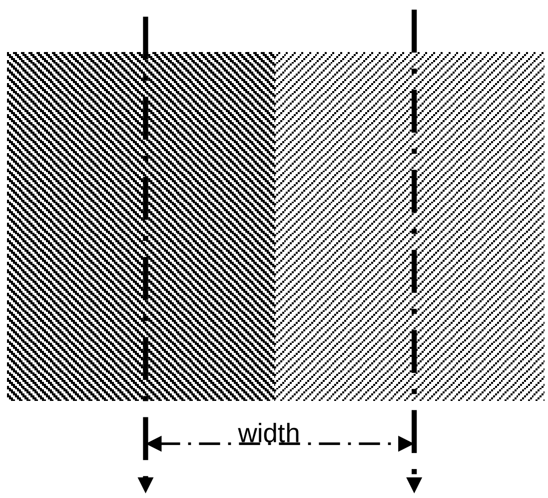
Various methods have been proposed and used for the determination of the optimum width of the coarse search strip. The results obtained by these methods are widely varying because of their dependency on the ability of the testing persons. Also, some methods make assumptions about density functions. These assumptions are not very solid. All of these methods require a substantial number of experiments to obtain useful data.

A new method is proposed which, while reducing the testing effort considerably, removes as much dependency from the testing person's ability as possible. The method can also be applied to multiple antenna beacons. The results provided are at least as accurate and reliable as the results obtained by earlier methods.

KEYWORDS: Avalanche beacons, Search strip, Field tests.

1. INTRODUCTION

The width of a search strip is equal to the lateral distance between individual rescuers searching an avalanche for buried victims :



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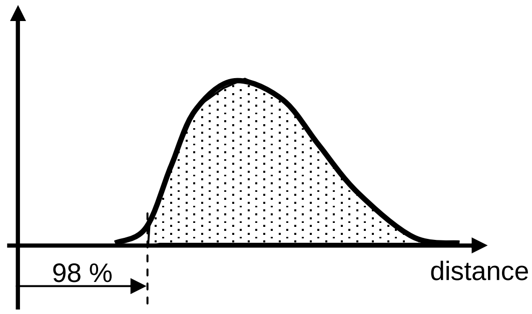
The wider the search strips, the more area can be covered within a given time span. However, widening the search strip also increases the probability that a buried victim is not detected. Since the actual range of a beacon is always dependent on the relative orientation of the transmit and receive antennas, there is no guaranteed minimum range.

For best probability of survival, the time taken for searching a given area must be balanced against the probability of missing a buried victim. This concept has been introduced by Walter Good, see Good (1986). From an analysis of typical avalanche accidents, Walter Good concluded that the half width of the search strip should be made equal to the range at which a beacon makes contact in 98% of the cases. The probability of not detecting a buried victim then is 0.0004, and this is balanced against the search time.

There are three known methods for determining the half (or full) width of the search strip:

1.1. <u>Direct use of measurement statistics</u>

The range of a beacon is determined by a sufficient number of experiments. The experiments are conducted by several individuals and with arbitrary orientation of the transmitting and receiving beacon antenna. A typical shape of the probability density function of the results obtained looks like this:



For examples of such curves, see [2], pg 41 – 45.

1.2. <u>Assuming a normal (Gaussian) density</u>

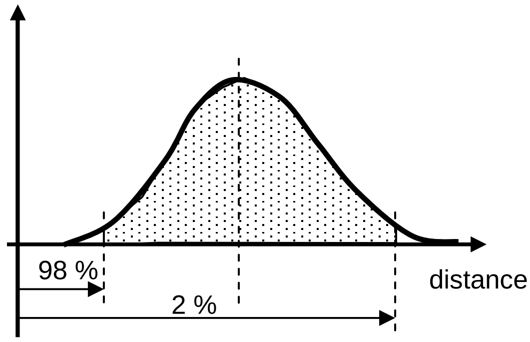
For calculations, the density is assumed to be normal (i. e. Gaussian). For that particular density function, the 98% range is pretty exactly equal to the mean minus two times the variance. This is accurate if the density is nearly normal, but less reliable for other density functions.

1.3. <u>Fitting statistics</u>

It was soon observed that the densities obtained from experiments were not normal. This is due to the fact that the testing persons had a natural tendency to obtain "good" range results and thus introduced some involuntary bias. Also, at the short end, the test setup is prone to incorrect results for reasons to be explained later. The results obtained are therefore fitted to a normal density by mirroring the upper part of the curve about the mean (see next figure).

Then, it was determined from field test results that, for most beacons, the 98% range was close to 20% of the 2% range. Since results at the upper end of the range proved to be much better reproducible, a new rule was established stipulating that the width of a search strip should be 40% of the maximum (i. e. 2%) range.

Evidently, this rule is more conservative than the first one. For practical purposes, it may even be too conservative. The time required to search a given area will be longer, thus reducing the probability of finding a buried victim in due time.



2. RELATIVE ANTENNA ORIENTATION

The wide variance of the traditional test results and the asymmetry of the densities obtained are mostly due to the influence of the relative antenna orientation.

The theory of electromagnetic fields states that, in the near field, the strength of the magnetic field produced by some transmitter is inversely proportional to the 3^{rd} power of the distance from the transmitter. Thus, doubling the distance reduces the field strength to one 8^{th}, or, inversely, at one half of the original distance the magnetic field is 8 times stronger.

At the frequency used by avalanche beacons, i. e. 457 kHz, the near to far field transition is at about 104 meters. For all practical purposes, avalanche beacons can be considered to operate in the near field only.

The voltage induced in the antenna coil of a receiver is proportional to the integral of the normal, i. e. perpendicular, component of the magnetic field over the surface bounded by the antenna coil windings, multiplied by the permeability of the local space. Thus, if the plane of the antenna coil windings is perpendicular to the field lines, the induced voltage is maximized. If the plane of the antenna coil windings is parallel to the field lines, there is no voltage induced at all.

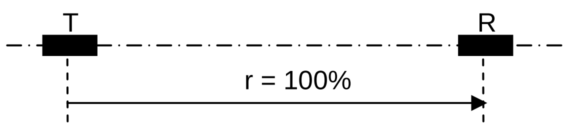
2.1. Uniform distribution

Test persons have a natural tendency to hold the receiving beacon horizontally in front of them. Transmitting beacons may be buried in few different orientations, since it is very cumbersome to run a test with a uniform distribution of transmitting beacon orientations. This introduces a bias into every test made.

2.2 Maintaining relative orientation

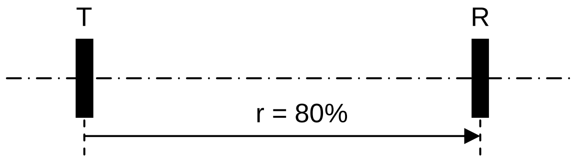
Even if the problem of uniform distribution of relative antenna orientations is solved, there remains the problem of the sensitivity of the results on the accuracy with which the relative orientation is maintained during the search. Let us first have a look at three important relative orientations :

The coaxial orientation provides the best results. The strength of the transmitted field has its maximum on a line, which passes through the axis of the antenna rod. The plane of the receiver antenna coil windings is perpendicular to the field lines, providing a maximum of induced voltage.



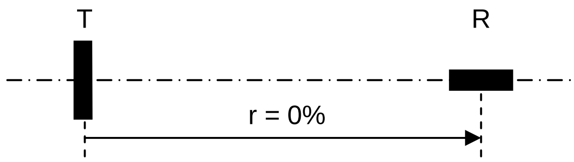
Measurements taken with coaxial antenna orientation provide the most consistent results. If one beacon deviates slightly from the coaxial orientation, the voltage induced in the receiver antenna coil windings will change with the cosine of such deviation. The cosine of 20° e. g. is 0.94, so deviations up to ±20° from the reference orientation will only introduce changes < 6% in the received signal, which is equivalent to a change of about 2% in range.

The parallel orientation provides shorter range. According to the laws of magnetic fields, the field strength at equal distance is reduced to half of the field strength in a coaxial position. Since, in the near field, the field strength can be considered proportional to one over the 3^{rd} power of distance, the range is reduced to one over the 3^{rd} root of 2, which is 0.79.



Note that, independently of the orientation of the buried transmitter, the searching person can always orient the receiver such that the antenna coil windings will be perpendicular to the field lines. Thus, the parallel orientation represents the worst of the cases that can always be achieved.

The perpendicular orientation produces the worst of results: zero range. This is due to the fact that now all the lines of the magnetic field are parallel to the plane of the receiver antenna coil windings, and thus there is no voltage induced in the coil.



Slight deviations from this orientation produce very large changes in the induced voltage, since it is proportional to the sine of the deviation. The sine of 0° is 0.00, and the sine of 20° is 0.34. Also, at a distance below a few Meters, stray effects may lead to some voltage being induced in the receiver antenna even when it is perfectly perpendicular. These are the main reasons for the asymmetry of the range densities obtained in field tests with "arbitrary" beacon orientation. Testers will never be able to maintain a perfectly perpendicular antenna position while performing the experiment, and they also have a natural tendency to orient the beacon so they will always hear some signal. If there were no stray effects, and if the orientation would always be perfect, the range densities obtained would have to extend down to zero distance!

3. A NEW APPROACH

3.1 Basic considerations

In order to eliminate the variance due to difficult experiments and to minimize the testing efforts, we propose the a new method for establishing the width of a search strip:

If a perpendicular antenna orientation is permitted for the search, the results can be disastrous. It is therefore considered reasonable to expect the searching person to always try different orientations of the receiving beacon until contact is made.

Beacon range measurements are done with coaxial antenna orientation. This eliminates (almost) all variance due to deviations from the stipulated antenna orientation. There will still be variance due to different type beacons, individual beacon receiver sensitivity, test person's hearing ability etc. Assuming a series of experiments with the same beacons but with different users, we expect the results obtained to be close to normally distributed and the variance to be less than 10% of the mean. As a starting point, we take the 98% range obtained from these experiments (The 98% range is the mean minus twice the standard deviation).

Now, we adjust the value for parallel antenna orientation. As stated above, this reduces the range to about 80% of its original value.

A second adjustment is made for any deviation from the perfectly parallel orientation. Allowing the searching person to deviate by ±60° from the parallel orientation, this reduces the received signal to 50%, which is equivalent to another reduction of the range to 80%. Note that this brings the allowed orientation to within ±30° of the disastrous perpendicular orientation! This deviation of ±60° provides for 50% coverage of the full solid angle of 4π.

A third adjustment is made for variations due to other parameters such as transmitter battery voltage, transmitter and receiver temperature etc. Assuming the total influence of these to attenuate the received signal by another 50%, there is again a reduction in range to 80%.

Combining all these adjustments, we obtain a usable range of

$$(98\%\ \text{range}) \cdot 0.80 \cdot 0.80 \cdot 0.80$$

which is 0.50 times the 98% range. This then is the half width of a search strip. We therefore propose the following rule of thumb for determining the full width of a search strip:

The width of a search strip is equal to the 98% range obtained from a sufficient number of experiments made with a coaxial antenna orientation.

3.2 Multiple antennas

The reasoning can be extended to multiple antenna beacons:

The signal received by a single antenna beacon is invariant to rotation about the antenna axis. Assuming orthogonal antennas, equal antenna sensitivity and vector addition of the signals from the individual antennas before evaluation, the following rules can be applied:

The signal received by a two-antenna beacon is invariant to rotation about the axes of the two antennas, and the signal received by a three-antenna beacon is totally invariant to rotation about any axis.

So, for example, for a beacon with two orthogonal antennas, consider a user with equivalent ability (or degree of cooperation) to achieve closer matching to the perfectly parallel orientation. To put this in figures, assume the effect to be equivalent to reduce the solid deviation angle from the desired orientation by a factor of two.

The full solid angle is 4π steradian (see Wildi (1991)). Letting a user deviate by ±60° with a single antenna beacon is equivalent to the deviation range covering a solid angle of 2π steradian. So, with a two-antenna beacon, the equivalent deviation range would cover 1π steradian. The worst case signal is obtained when at the outer border of the deviation range, i. e. at 60° for a single antenna beacon and at 41.4° for a two-antenna beacon. The respective cosines and correction factors are

.5	0.80	for 60.0°
.75	0.90	for 41.4°

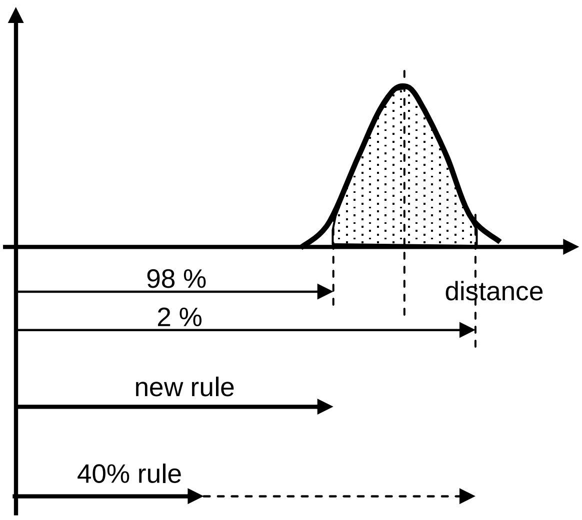
So the total correction factors become

antennas	parallel orientation	user cooperation	battery temperature	total
1	0.8	0.8	0.8	0.50
2	0.8	0.9	0.8	0.57
3	0.8	1.0	0.8	0.64

4. DISCUSSION

4.1 Comparison to the 40% rule

The following graphics provide a likely comparison between the 40% rule assuming no user cooperation to the new rule assuming a minimum of user cooperation:



Assuming a typical set of experiments with coaxial antenna orientation, the variance would be about 10% of the mean. The search strip widths obtained would then be

new rule: (mean – (2 • σ)) = mean • 0.80
40% rule: (mean + (2 • σ)) • 0.4 = mean • 0.48

The ratio of the widths is 1.667.

Evidently, the 40% rule is more (too?) conservative. Most of the difference can be attributed to the fact that it does not assume any cooperation from the part of the user.

4.2 Comparison to results from field tests

It is interesting to do a cross check with the results obtained in a series of field tests organized by the Swiss Federal Institute for Snow and Avalanche Research (Krüsi (1998)). The table on the next page compares the full search strip width obtained by the four methods, namely

- Direct use of measurement statistics. The 98% range is assumed to be equal to the upper boundary of the minimum range bin. If the bin has a lot of entries relative to the next bin to the right, then the center of the bin is assumed to be the 98% range.
- Assuming a normal density (the variant chosen in (Krüsi (1998))
- Fitting statistics (40% of the 2% range). The 2% range is assumed to be equal to the lower boundary of the maximum range bin.
- This method, where the variance of the results is assumed to be 10% of the mean, and the 2% range is assumed to be equal to the lower boundary of the maximum range bin, i. e. the 98% range is .60 times the lower boundary of the maximum range bin.

The results from localization tests that were also part of the test setup have not been considered since those tests served a different purpose.

Whereas the normal and the fitted figures compare pretty well for the ARVA, Ortovox and Tracker beacons, they differ considerably for the Barryvox and Pieps beacons. This may to some extent be due to the fact that the densities obtained for the latter are closer to normal in shape.

For the Barryvox, the estimates by the new method are in between the figures obtained by assuming a normal density and the figures obtained by fitting. For all the other beacons, the figures estimated by the new method are lager than the other ones. But the estimates obtained with the new method fit pretty well with the figures derived directly from the histograms for all beacons.

Comparison of results on the base of data obtained from field tests by the Swiss Federal Institute for Snow and Avalanche Research:

	Country	Direct	Normal	Fitted	This Method
ARVA	F	30.0	14.6	28.0	42.0
	CH, I, A/D	20.0	16.8	18.0	27.0
	CH, I, A/D	20.0	18.4	18.0	27.0
Ortovox	F	40.0	37.6	28.0	42.0
	CH, I, A/D	30.0	20.6	22.0	33.0
	CH, I, A/D	30.0	21.4	22.0	33.0
Tracker	F	25.0	16.8	16.0	24.0
	CH, I, A/D	20.0	16.6	14.0	21.0
	CH, I, A/D	20.0	19.6	14.0	21.0
Barryvox	CH	60.0	59.6	26.0	39.0
	CH	40.0	50.2	26.0	39.0
Pieps	CH, A/D	30.0	30.8	22.0	33.0
	CH, A/D	30.0	29.4	22.0	33.0

5. CONCLUSION

The traditional methods for determining the width of a search strip suffer from the fact that the measurements taken at the lower end of the density function are subject to large variations from imperfect test settings (relative antenna orientation, user bias). They also require a rather large number of samples to be taken. The second and the third method are delicate because they make assumptions about the shape of the density function that may deviate to some extent from reality. The new method for evaluating the width of a search strip should provide more consistent results with fewer samples since it is based on an experimental setup with reduced inherent variance.

REFERENCES:

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