Performance and Cost Trade-offs in LF H-Field Antenna Design

Erik Johannessen, Andrei V. Grebnev
Megapulse, Inc.
Bedford, MA 01730

BIOGRAPHIES

Erik Johannessen received an MBA in marketing from Bentley College in 1986. He worked in a variety of capacities ending as project coordinator for new product development at International Navigation from 1974–81. Mr. Johannessen has been connected with Megapulse since 1981 where he is currently a Vice President. Mr. Johannessen is also President of A/O Gradient.

Andrei V. Grebnev received an MS degree in radioelectronics engineering in 1981 from Moscow Aviation Institute, Moscow, USSR. From 1981 until 1991 he worked at the same Institute as Senior Research engineer and later as a Chief of Receivers Laboratory. In 1991, he joined the Research Center of Russian Radionavigation Committee, where he worked as a Senior engineer and Deputy Chief of Radionavigation Systems Operation Department. Since 1993 he has been employed by Megapulse, Inc. as a Senior Hardware Engineer, where he is responsible for the design of combined loop antennas and hardware for newly designed receivers.

ABSTRACT

Future portable applications of LF or integrated LF-GPS receivers will require that the receivers be lightweight, compact and low-power. The H-field antenna advantages are low sensitivity to precipitation static and to E-field interferers, as well as simplicity of installation (low profile and no grounding) making this type of antenna attractive in many applications. Pulse phase systems such as Loran require the use of crossed loops to provide an omnidirectional antenna pattern. The ability of an H-field antenna to receive a signal of any given field strength is a function of the amount of ferrite material, geometry of the crossed loops, and permeability of the material. Increased ferrite material yields better performance at the expense of increased cost, size and weight. This paper evaluates trade-offs between cost and performance of H-field antennas as designed for the Loran system. Relationships between field strength, noise levels, and antenna design are analyzed. Experimental results indicate that in the presence of high field strengths or in applications of satellite augmentation significant reductions in size and cost are readily achieved.

INTRODUCTION

The advantages and disadvantages of loop antennas have previously been well described [1,2]. The introduction, by Megapulse, Inc., of an experimental Loran-C loop receiver [3] demonstrated the ability to solve problems such as bidirectional pattern and signal phase inversion which are caused by the lack of omnidirectivity. Design considerations that must be addressed due to the low effective heights of loops have also been discussed [4].

One of the main parameters determining the performance of any Loran receiver is the Signal-to-Noise Ratio, or SNR, at a given signal strength. It can be determined as:

$$SNR = \frac{Signal}{Atmospheric\ Noise + Interference + Receiver\ Noise} \qquad (1)$$

The effect of atmospheric noise and interference can be minimized by a proper selection of the bandpass filter and adequate number of notch filters. The effect of the receiver noise, or loop antenna preamplifier noise, is minimized by matching the output and input parameters of loop antenna and preamplifier to obtain the minimum equivalent noise level on the input of the preamp. The signal delivered by the loop antenna is primarily determined by the volume of ferrite material, length-to-diameter ratio of the ferrite, and initial permeability and obtains its maximum at *an optimum length-to-diameter ratio* (m_{opt}) [5]. Calculations show that for a ferrite material with initial permeability μ=1000, m_{opt}=108. Thus, if the ferrite has a diameter of 1 cm, its optimum length is 108 cm! Such a geometry is unacceptable for a compact hand-held receiver.

This paper discusses the issue of trade-offs between loop antenna performance and its size, weight and cost. Three different frame configurations are discussed in the next section. A section follows which discusses the test set-up. The final two sections are a presentation of the test results and some observations and conclusions.

LOOPS TESTED

Three loop antennas were compared on the basis of performance and cost. All antennas used the same preamplifier which varied only in adjustment setting to ensure lowest equivalent noise on the input. The number of turns in the windings varied slightly from loop to loop but the variation was not more than 30% from largest frame to smallest. Therefore, the principal difference between antennas was in frame geometry and dimension. The three tested frames are depicted in Figure 1.

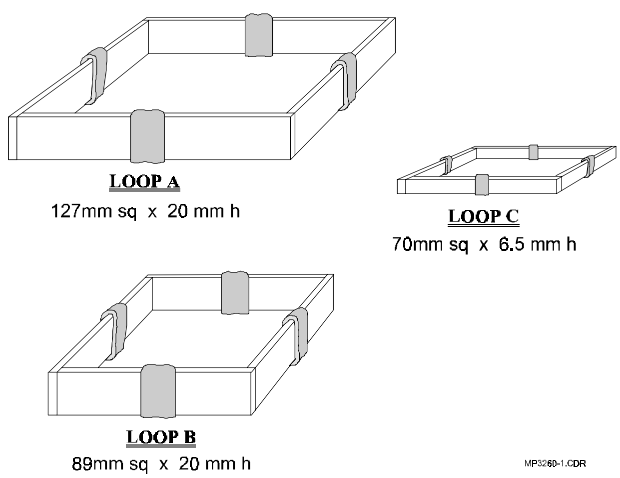


Figure 1.

All of the frames used commercially available ferrite material. Four identical bars 4 mm thick were arranged in the square as shown in the figure. Parameters for the total frame assembly are as follows:

	Vol (mm^3)	*Weight (gm)*	*Cost ($)*
A	40,640	200	16.00
B	28,480	140	11.00
C	7,280	36	4.00

DATA COLLECTION

A block diagram for the data collection is shown as Figure 2. The loop antennas were mounted on a motor-driven platform on the roof of the Megapulse, Inc. facility in Bedford, MA. Twelve notch filters were used to minimize the influence of CW interferers. The receiver used for data collection was the Accufix 520 which provides measurements of Signal-to-Noise Ratio (SNR), signal strength, and Envelope-to-Cycle Difference (ECD).

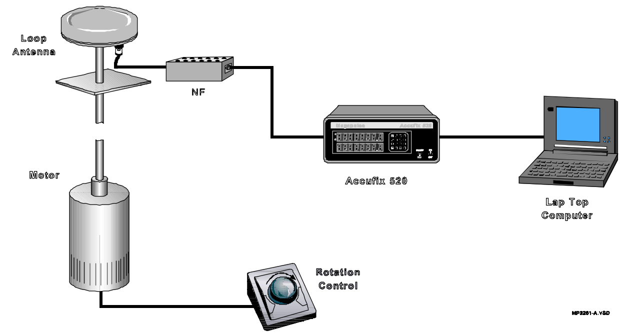


Figure 2.

Because the Accufix 520 is designed for whip antennas, only one pair of the crossed loops was used. Restrictions of equipment availability required that data sets be taken serially. Data was collected for a twenty-four hour period with the antenna oriented to the maximum of the positive lobe with respect to the remote station being measured. In the case of the Master and 4th secondary (Dana, Indiana) the relative bearing angles from the test site were small enough that the data could be collected simultaneously. The data was therefore collected over a 12 day period (four orientations for three antennas). Information on the stations is as follows:

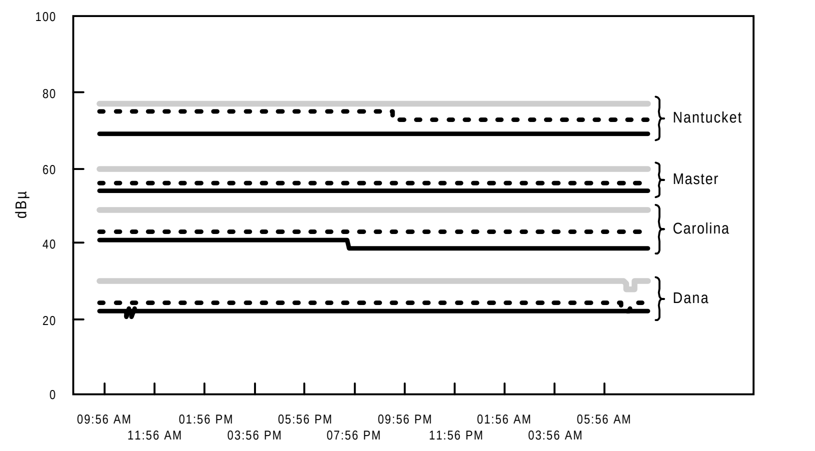
	Power	*Dist.*	*Path*
Caribou (S1)	350 kW	549 km	land
Nantucket (S2)	400 kW	170 km	mixed
Carolina (S3)	550 kW	1100 km	mixed
Dana (S4)	400 kW	1390 km	land
Seneca (M)	800 kW	458 km	land

TEST RESULTS

The receiver was set up to output one data message every 180 seconds. The data file was imported into a spreadsheet and a series of graphs created. These graphs are presented as Figures 3-11. Field strength of the stations is shown in Figure 3. For clarity, the Caribou secondary is omitted from the Figure. Caribou data overlapped the lower range of Master and upper range of Carolina. The signal level (with a few minor unexplained deviations) is seen to be constant. The effect of decreasing antenna frame size (in other words, effective height) is well seen on each station.

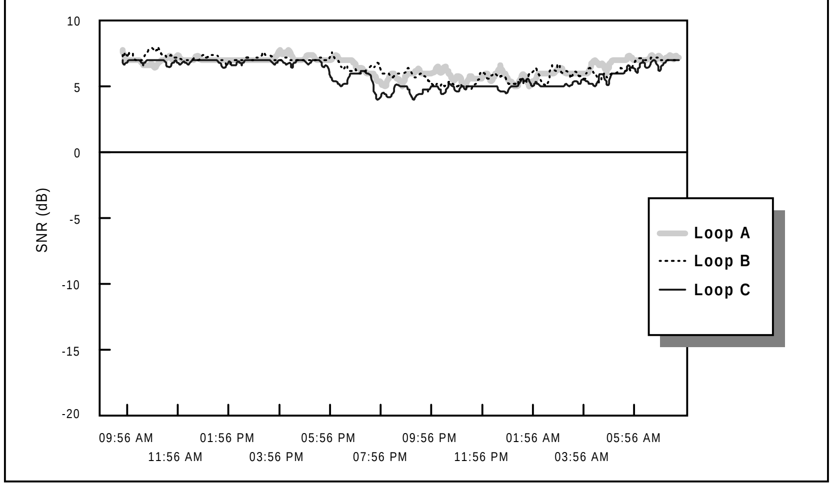
Constant signal level and uniform receiver noise implies that SNR changes result from changing levels of atmospheric noise and interferers. Indeed, the day-night effect is clearly shown in Figure 5.

Figure 3. Field Strength
(Master and three Secondaries)



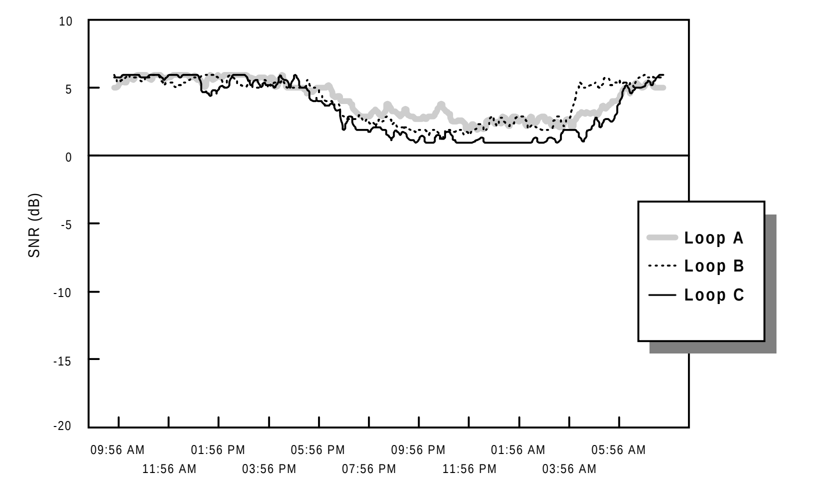
MP3270-1.VSD

Figure 4. Master (Seneca)



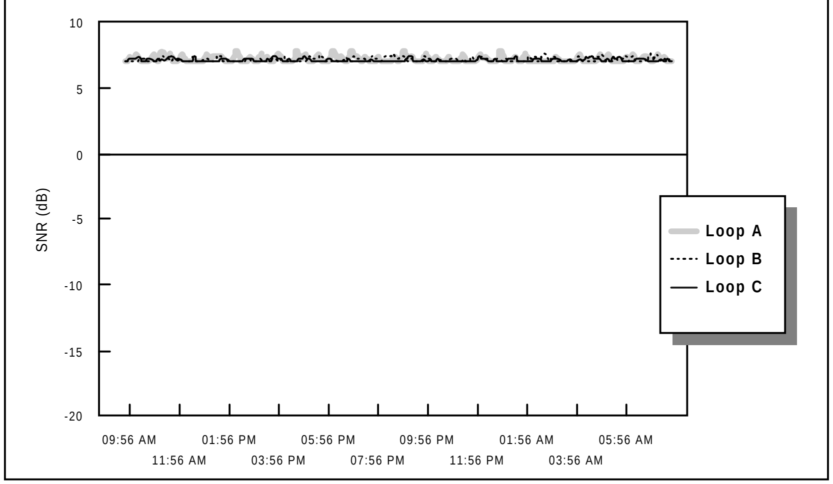
MP3265-1.VSD

Figure 5. Secondary 1 (Caribou)



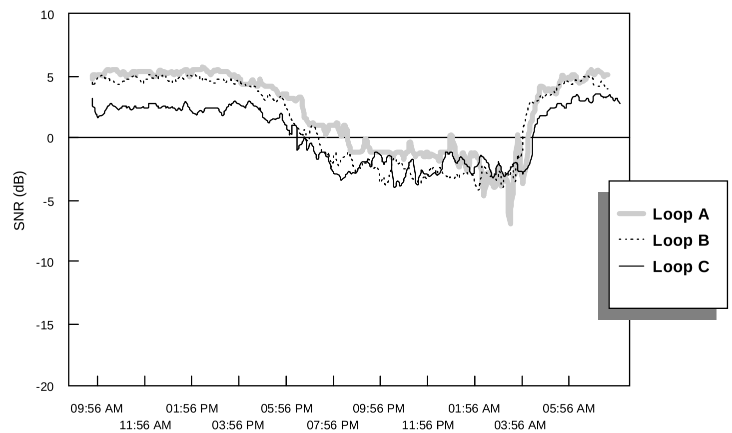
MP3266-1.VSD

Figure 6. Secondary 2 (Nantucket)



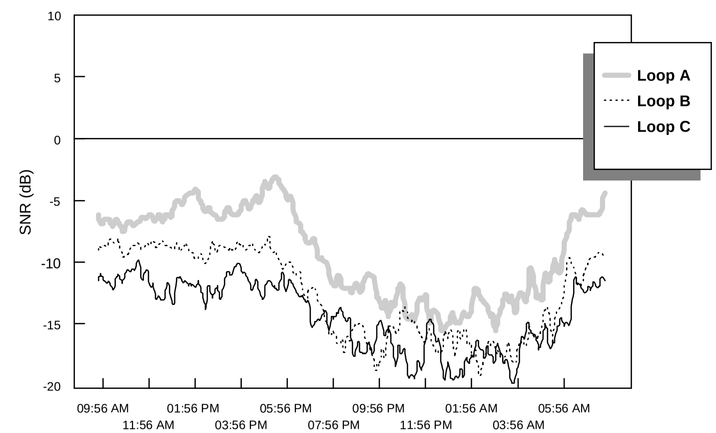
MP3267-1.VSD

Figure 7. Secondary 3 (Carolina)



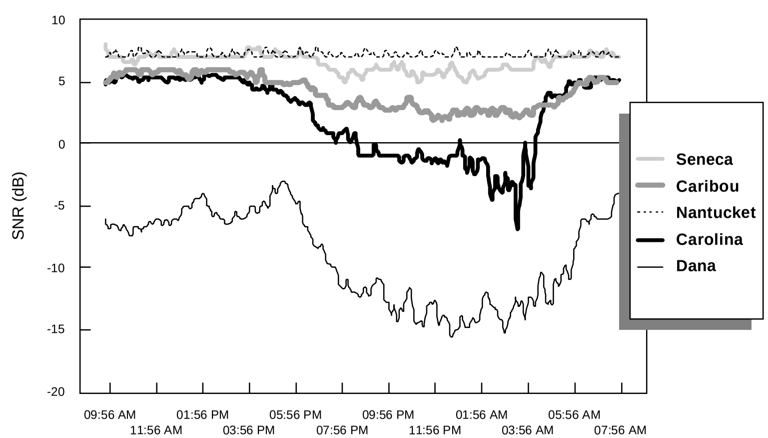
MP3268-1.VSD

Figure 8. Secondary 4 (Dana)



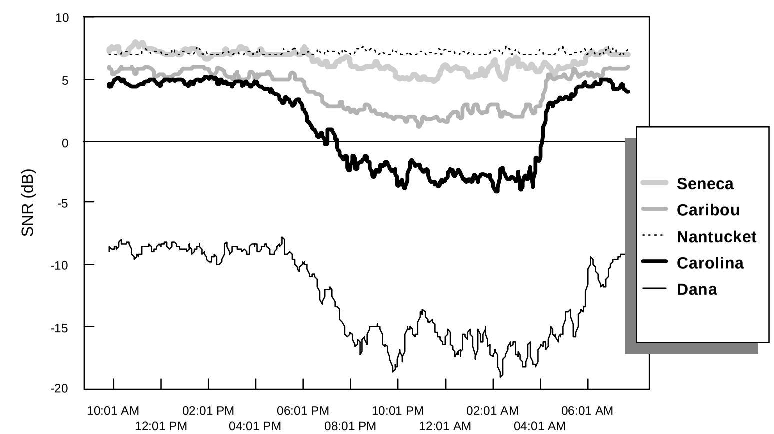
MP3269-1.VSD

Figure 9. Loop A - 24 Hour Data Set



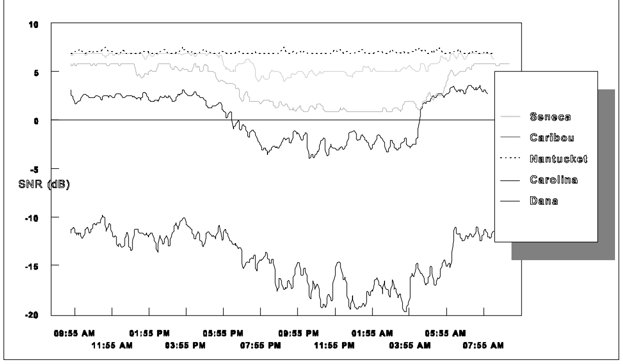
MP3263-1.VSD

Figure 10. Loop B - 24 Hour Data Set



MP3262-1.VSD

Figure 11. Loop C - 24 Hour Data Set

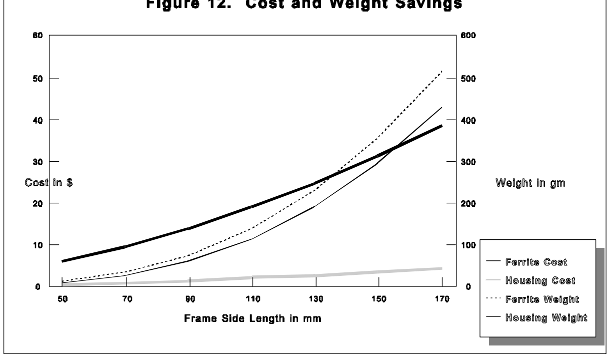


The reduction in frame size that results in lower output signal level also results in a proportionally decreased level of atmospheric noise and interferers. Receiver noise, however, is constant and will ultimately cause degradation of SNR. This effect is best seen in Figures 7 and 8. The lower signal levels of the remote stations means an approximate loss of 3 dB on Carolina and 6-7 dB on Dana between loops A and C. These losses coupled with the day-night effect suggest that frame size considerations are important in applications dependent upon reception of remote stations.

CONCLUSION

The length-diameter ratios of Loops A and C are close to equal. The Loop B ratio is somewhat less. The data presented in Figure 3 for field strength suggests that the minor performance difference between Loops B and C is more attributable to change in length than change in volume (Loop C having ¼ to _ the ferrite material of Loop B). A graph based on the length-diameter ratio of Loops A and C is presented as Figure 12 to show the effective savings in cost and weight as frame size is reduced. The graph assumes an annual production volume of 10,000 units. Cost information is the direct cost to a manufacturer. Savings can be accrued

Figure 12. Cost and Weight Savings



both from reduced ferrite material and a smaller radome. It is shown that the total weight can be expected to decrease by 75% from 480 grams to 120 grams and that the direct cost is reduced 78% from $19.00 to $4.20 per unit.

The collected data indicates that savings are a function of user requirement. Generally, stations of sufficient field strength are more affected by day-night effect than frame size. Users that require a low number of stations or operate in a local area would experience greater benefits. Use of Loran in pseudo range or DGPS applications (such as Eurofix) have the greatest savings potential. Conversely, users dependent upon stations of marginal reception are greatly affected by frame size.

System owners or operators can benefit by ensuring sufficient signal strength exists in desired areas of coverage. Availability and accuracy are enhanced through reception of remote stations. Lower cost, weight and size of user equipment will increase the number of system users. High field strengths also permit use of very small loops to meet special applications.

This experiment also demonstrated that a single front-end design is capable of accommodating variation in frame size. Further research is needed on limits of miniaturization and on length-diameter ratios.

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