Wideband Tapered-Slot Antenna with Corrugated Edges for GPR Applications

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Abstract — **A novel wideband tapered-slot antenna for GPR applications is proposed. A conventional approach to reduce unwanted interactions between the antenna and the ground surface requires extensive microwave absorbers treatment. For the same purpose we propose to use corrugations along the antenna edges. The corrugations improve directivity and wideband matching of the antenna with free space retaining also good radiation efficiency. Further improvement of the antenna performance has been achieved by patching the corrugated areas of the antenna with the resistance card strips. The elimination of the foam-type absorbers makes the antenna more robust and easier in fabrication.**

I. Introduction

Clutter is one of the main factors limiting performance of the ground penetrating radar (GPR). Significant part of the clutter especially at short times/distances is produced by the interaction of the antenna system with the ground surface. To reduce the influence of the near-field effects arising when the antenna is placed close to the ground or the wall surface, resistive loading can be used. To this end, the flares of TEM horns and bowtie antennas are covered usually by the microwave absorber blocks. The absorber treatment improves the antenna performance at the expense of some drop in the radiation efficiency. Besides, the antenna employing the foam-type absorbers becomes rather fragile that may be inconvenient in practice.

The resistive loading of GPR antennas can be replaced partially by a capacitive loading [1] though absorber blocks have been used in the proposed bowtie antenna as well. Besides, the resistive loading can be implemented by integrating resistive sheets into the antenna geometry. So, the cards with tapered resistive profile had been successfully utilized in the slotline-bowtie TEM horn hybrid [2].

Another antenna that became popular during the last few years is a tapered slot antenna (TSA). This antenna of the traveling wave type looks like a printed circuit board thus it is easy to fabricate and well suited for constructing antenna arrays. For better performance, the reflection from the antenna opening should be also suppressed by microwave absorber rods attached to the antenna flares along their edges.

A simple modification of the TSA based on introducing corrugations on the antenna edges results in improved radiation pattern of the millimeter-wave TSA's [3]. This may be attributed to a better impedance match of the antenna to free space.

We have found that edge corrugations of the TSA are useful in GPR applications, too. The antenna with corrugated edges exhibits a lower level of clutter in the received signal when placed near the ground surface. Further improvement has been achieved by patching the corrugated area of the antenna with strips of the resistive sheet.

The modified antenna remains extremely thin, robust, low-cost and easy to fabricate like the original one. As far as the GPR applications are concerned, the modified antenna outperforms the TSA with usual foam-type microwave absorber treatment.

II. Overview of the Tapered Slot Antenna with Corrugated Edges

The tapered slot antenna for experimental tests has been built on epoxy substrate using a photo-etching method as shown in Fig. 1. The substrate thickness was of 1 mm.

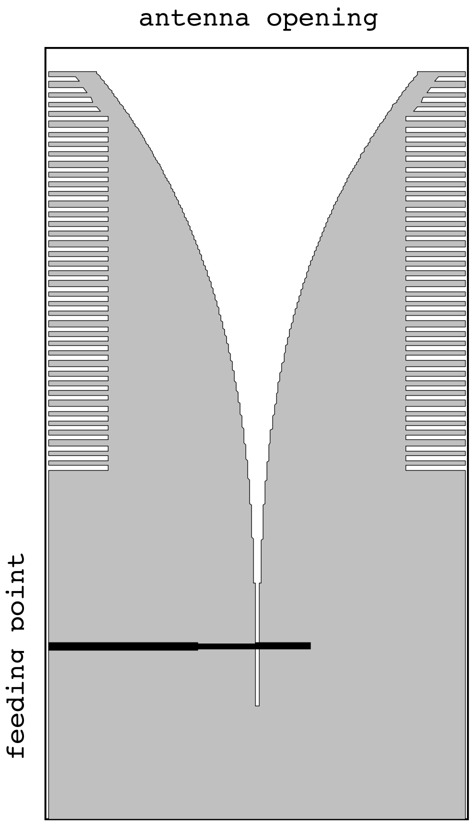

Fig. 1. A tapered slot antenna with corrugated edges and the 4th order Marchand balun.

The antenna is fed through the 4th order Marchand balun that serves at the same time as a bandpass filter and a microstrip-to-slotline transition. The balun has been designed for the frequency band of 1 to 4 GHz. To provide better impedance transition between the balun and the aperture of antenna, a Vivaldi taper has been used. For higher frequency bands, low-loss substrate like Duroid 5870 has to be preferred. However, in this case the antenna is not rigid enough and therefore needs supporting rods.

The corrugated edge consists of equal strips and slots. Their dimensions had been chosen experimentally as about 20 mm in length and 1.5 mm in width. For further reducing the internal reflections of the antenna, the corrugated areas in Fig. 1 have been covered by strips of the resistive sheet with constant resistivity of 200 Ω per square. Overall dimensions of the fabricated antenna are of 245 mm to 130 mm whereas its thickness is less than the connector size.

For the comparison purpose, another antenna of the same dimensions without corrugations has been built. In that antenna, the resistive strips have been replaced by square rods of the foamy microwave absorber with the cross section of 20 to 20 mm.

III. Evaluation technique

To compare the performance of different GPR antennas from the viewpoint of clutter produced by their non-ideality, we employed the technique described in [4]. The procedure includes three stages.

1) The measurement system consisting of a wideband step-frequency radar or vector network analyzer and the tested antenna system should be properly calibrated. Simplified free space calibration technique described in [4] or more complicated methods presented in [5]-[6] can be used.

2) The metal plane used for the calibration is shifted from the reference plane by a fixed distance, e.g. 2-3 cm. This is close to possible deviation of the elevation of the antenna over the ground in practical applications. As the metal plane represents here a single reflecting object, its response can be subtracted from the measured frequency domain signal in a form of a complex exponential term. Both modulus and phase of this term have been represented by polynomials of degree 2 or 3 as functions of frequency. The parameters of interpolating polynomials have been computed separately for modulus and phase by a numerical fitting procedure that can be easily carried out using e.g. **polyfit** and **polyval** functions of MATLAB.

3) A residual left after subtracting the dominant reflection from the metal plane can serve as a measure of clutter produced by the non-ideality of the antenna system. For convenience, this residual can be transformed into a synthetic range profile by the inverse discrete Fourier transform (IDFT). From the range profile one can determine distances corresponding to significant clutter components. Small underground targets buried at these depths can be obscured by clutter.

IV. Experiments

All the measurements had been carried out using a vector network analyzer operating in the frequency band of 1 to 4 GHz that corresponds exactly to the frequency band of the designed TSA. The signal processing technique outlined in the section III has been applied to the data obtained using both monostatic and bistatic antenna types. The reflected signal of a metal plane shifted by 2 cm away from the reference position has been processed to evaluate the level of clutter.

The synthetic range profiles calculated from the reflection coefficient of the shifted metal plane before and after subtraction of the dominant response are shown in Figs. 2-4. All three figures correspond to the monostatic antenna measurements.

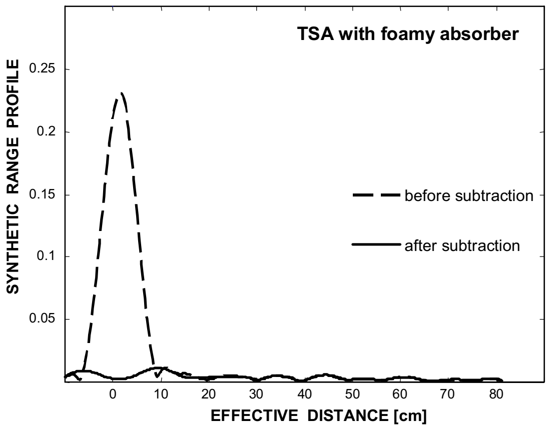

Fig. 2. Synthetic range profile of the signal reflected from the metal plane for a monostatic TSA with foamy absorber.

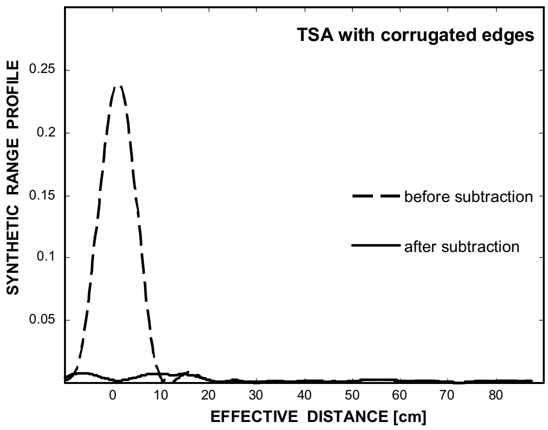

Fig. 3. Synthetic range profile of the signal reflected from the metal plane for a monostatic TSA with corrugated edges.

The conventional TSA with foam-type absorbers can be considered as good enough for GPR because only small amount of clutter is left after subtracting the dominant reflection as seen in Fig. 2. The antenna with corrugated edges performs even better. The clutter at all distances in Fig. 3 is a little smaller than that for the TSA with microwave foam-type absorbers.

For additional comparison, a similar plot has been obtained also for the TEM horn with the microwave absorber treatment on its flares (Fig. 4).

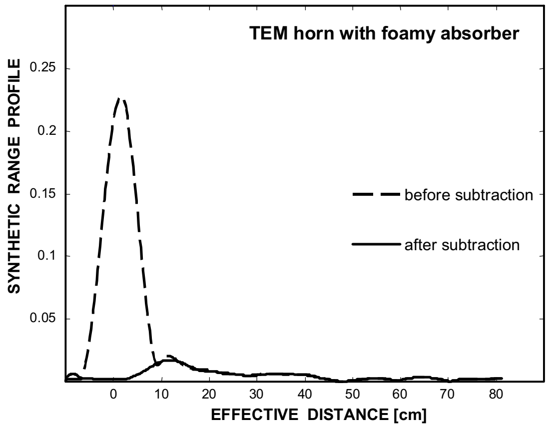

Fig. 4. Synthetic range profile of the signal reflected from the metal plane for a monostatic TEM horn.

The subtraction procedure is apparently less effective for the TEM horn as compared to the both tapered slot antennas. The clutter in Fig. 4 is rather high especially at short distances (near 10 cm) and thus it can mask shallow underground targets.

The measurements carried out with bistatic antennas of all mentioned types showed very similar results. Again, the highest level of clutter had been obtained for the bistatic TEM horn whereas only small difference can be noticed between the both TSA's.

Naturally, the comparative study of such kind is not exhaustive. The performance of any GPR antenna has to be evaluated also from the viewpoint of sensitivity to deeper targets because only the signal/clutter ratio is really important. That is why we have measured also the signals reflected from the metal plane placed in free space at a distance of about 40 cm from the antenna system. The experiment has been carried out using two similar bistatic antennas constructed respectively from TSA with corrugated edges and from conventional TSA with microwave absorbers. In Fig. 5, synthetic range profiles calculated by the IDFT from the broadband signals received by these antennas are shown. It is worth noting that in this case the free space calibration procedure has not been applied.

As the reflecting metal plane is placed rather far from the antenna aperture, two peaks can be observed in the synthetic range profile. First of them arises due to direct leakage of the wave between the transmitting and receiving antennas whereas another one corresponds to the target. Fig. 5 demonstrates clearly advantage of the TSA with corrugated edges. The direct leakage is lower and the response of the target is higher compared to the bistatic TSA with absorbers.

Perhaps, suppression of clutter in the conventional TSA antenna with microwave absorber treatment is achieved at the expense of the radiation efficiency. Besides, better sensitivity of the TSA with corrugated edges can be explained by higher directivity of the corrugated tapered slot antenna as is stated in [3].

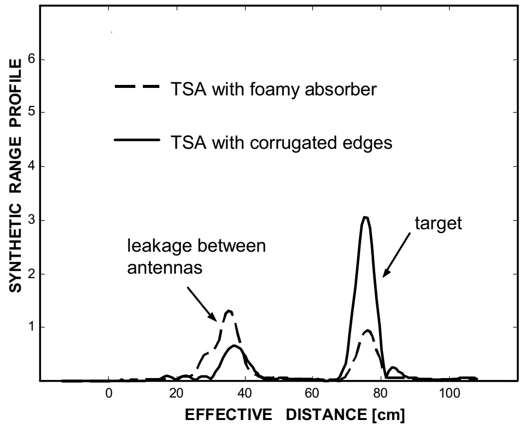

Fig. 5. Synthetic range profiles obtained by different bistatic TSA's for a remote metal reflector.

V. CONCLUSION

The tapered slot antenna with corrugated edges and resistive sheet strips patched on the corrugated areas has been proposed. In the step-frequency GPR applications, it demonstrates low level of clutter and high sensitivity that can be attributed to good directivity and radiation efficiency. Due to absence of foamy absorbers, the antenna is thin, robust, easy to fabricate and convenient to design antenna arrays for subsurface radars.

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