NEW DESIGNS OF CLASS *V* FLEXTENSIONAL TRANSDUCERS USING THE ATILA CODE

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SUMMARY

The principle of SONAR array as used in underwater detection consists of generating a sound wave which propagated into a fluid medium, and is then reflected from a target. The location and identification of the target can then be achieved through analysis of the echoes. The improvements sought in range and performance require the use of higher and higher power at lower and lower frequencies from radiators of reduced dimensions. At the present time, Flextensional transducers seem to offer a good solution. Two classes of Flextensional transducers are generally employed: classes *IV* and *V*. In the first case, the drivers consist of parallel stacks of ceramics. The shell provides the necessary pre-stressing. In the second case, the drivers are made from ceramics staves arranged to form a ring. The pre-stressing is achieved by wrapping the ring with glass fibres under tension. However, because it is no classical, the application of pre-stress in these two cases remains delicate and imprecise. The purpose of this paper is to propose and to analyse by the finite element code **ATILA**[1] an original class *V* Flextensional transducer that does not suffer from this drawback. This Flextensional transducer is made of a segmented ring on which are mounted conventional ceramic stacks arranged in an inscribed polygon. It would have the advantage of simple construction and easy pre-stressing. Several configurations will be analysed with a special emphasis on technical advantages of these new Flextensional designs.

INTRODUCTION

Classical piezoelectric transducers are length expander vibrators that are built with a ceramic stack bounded between a tailmass and a headmass. Such devices, the size of which is comparable to the acoustic wavelength, are bulky when used as low-frequency projectors. On the contrary,Flextensional transducers are generally wide-bandwidth, high-efficiency, high-power projectors which operate at low frequencies though they are small compared to the acoustic wavelength. To design these projectors, the mathematical analysis is difficult and the optimization is complicated by the large number of variables. The finite-element modelling is a very powerful approach to solve this problem[2,3], since a finite-element model is able to take simultaneously into account the assembling of 3-dimensional elements, the piezoelectric or the magnetostrictive effect, the fluid-structure interaction and the radiation damping[4]. The aim of this paper is to use the **ATILA** code for new Flextensional transducers designs. It includes finite-element models for various Flextensional transducers[5]. All the Flextensional transducers described in this paper used a polygonal ring (fig. 1). This basic transducer is made from a segmented ring on which are mounted conventional cylindrical ceramic stacks of diameter 50 mm, arranged in the form of an inscribed polygon. Each ceramic is driven in parallel in the k_{33} mode and the stacks are pre-stressed by central bolts. The stacks dilation involves radial vibration of the ring. The number of sides of the polygon is optimized and fixed up to 8 to have good radial displacement of the ring. In Sec. 1, the in-air modal analysis of the octagonal ring is described. Resonance frequencies, coupling factor and mode displacement fields are computed. In Sec. 2, two kinds of Flextensional transducers using the basic octagonal ring are defined: the asymmetrical type with one shell and the symmetrical type with two shells. In-air modal analysis and in-water harmonic analysis are also computed using a complete finite-element approach including a part of the fluid domain, restricted to the close nearfield and limited by a spherical boundary upon which special dipolar damping elements are attached[6]. An efficient extrapolation algorithm provides farfield quantities of interest. Computed transmitting voltage responses and directivity patterns are shown. All frequencies are normalized to the computed value of the fundamental resonance mode frequency of the octagonal ring in air. In Sec. 3, hydrostatic pressure problems are mentioned. New convex and concave shells are defined to try to solve the problems. In-air and in-water analysis of the new Flextensional transducers are computed.

1. IN-AIR MODAL ANALYSIS OF THE OCTAGONAL RING

Due to the geometry of this basic transducer, a fully 3-dimensional finite element model is necessary. However, because the **ATILA** code is able to take into account all the symmetries of the structure, only a part ($1/32^{th}$) of the whole transducer is modeled with symmetrical boundary conditions (fig. 2) to select the useful modes. Table 1 shows numerical results for the two first modes and their coupling factors.

Table 1: Normalized natural frequencies of the octagonal ring

Mode	Resonance Frequency	Coupling factor (%)
1	1.00	48
2	1.69	22

The displacement fields of the two modes are shown on fig. 3. The first mode is the dilation mode of the ceramic stacks with a great coupling factor and the second is the first flexure mode of the ring.

2. FLEXTENSIONAL TRANSDUCERS USING THE BASIC RING

2.1. In-air analysis

Two types of Flextensional are defined: one symmetrical and one asymmetrical. The symmetrical solution has two shells (fig. 4). It can been used for omni-directional SONAR array. The asymmetrical solution has only one shell and can provide directional radiation with a special array conception. In-air modal analysis has been computed using a complete 3-dimensional model, both for the shell and the octagonal ring. Tables 2 and 3 show the results for the first three modes.

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Table 2: Normalized natural frequencies of the symmetrical transducer

Mode	Resonance Frequency	Coupling factor (%)
1	1.08	37
2	1.80	14
3	2.05	13

Table 3: Normalized natural frequencies of the asymmetrical transducer

Mode	Resonance Frequency	Coupling factor (%)
1	1.01	29
2	1.09	40
3	1.89	2

2.2 In-water analysis

In-water analysis with the **ATILA** code requires a finite-element mesh of the structure as well as of the fluid domain, restricted to close nearfield by a spherical boundary (fig. 5). An appropriate damping condition is applied on this spherical boundary that surrounds the fluid mesh for absorbing the outgoing wave. Kinematic and dynamic continuity equations between displacement and pressure fields being enforced on the interface due to the variational formulation[7]. In-water harmonic analysis has been computed for the two transducers. Fig. 6 displays the transmitting voltage responses versus normalized frequencies in the axial and the radial directions. The maximum response is in the both two cases at reduced frequency 0.74. The first peak is related to the first in-air mode of the shell. The level is better for the asymmetrical transducer than for the symmetrical because it seems that, for the asymmetrical solution, the first shell mode is coupled with the first dilation mode of the ceramic stacks. Directivity patterns are also computed for three different reduced frequencies as shown on fig. 7. The maximum pre-stress which could be applied to the ceramic stacks is 30 MPa for the classical ceramics used in these applications. Thereby, the maximum acoustical power which could be generated is nearly 40 kW in both cases. That is the theoretical mechanical limitation. The maximum electrical field for the same ceramics is 450 V/mm. In this, the theoretical maximum acoustical power which could be generated is 30 kW.

3. HYDROSTATIC PRESSURE PROBLEMS

3.1.Static analysis

The Flextensional transducers modeled in the previous sections are uncompensated transducers. They can not operate at deep immersion because hydrostatic pressure involves some relaxing of the ceramic stacks pre-stressing. The purpose of this section is to define and to study a kind of shell that does not imply relaxing of pre-stressing. The first idea is to change the radius of curvature of the shell and use concave shell inside of convex shell. New concave shell was defined and used with the polygonal ring to design new Flextensional transducer. To make comparison easier, a convex-shell transducer was also defined. A simple static analysis which has been performed shows that with the convex-shell transducer, pre-stressing is lost while with the concave-shell transducer pre-stressing increases.

3.2 In-air modal analysis

In-air modal analysis has been performed and the results obtained are summed up in Table 4. A nice agreement is obtained between the two cases. It has to be pointed out that this behaviour is normal because the shells are the same and only their curvature orientation is different. Fig. 8 displays, for the two transducers, the first two modes which are the first and the second modes of the shell.

3.3 In-water harmonic analysis

In-water harmonic analysis has been computed. Fig. 9 displays the transmitting voltage responses versus reduced frequencies. These curves exhibit two tight peaks which are related to the two in-air first modes of the shell. The radiation of this transducer is almost omni-directional in this frequency range. According to the previous mechanical and electrical limitations, the maximum acoustical power generated is 3 kW. This transducer is less powerful than the previous one.

Table 4: Normalized natural frequencies of convex and concave-shell transducers

Mode	Resonance frequency		Coupling factor (%)	
Type	Convex	Concave	Convex	Concave
1	0,35	0,35	22	23
2	0,51	0,51	12	10
3	1,00	1,00	6	3

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CONCLUSION

This paper has presented a detailed analysis of the acoustical behaviour of new class-V Flextensional transducers, using the finite-element code **ATILA**. Hydrostatic pressure problems are mentioned and not completely solved. More investigations have to be done to define compensated transducers for greater depths. The large capability of the **ATILA** code to describe the in-air and in-water behaviours of structures was demonstrated and proves the interest of using finite-element code. The in-air and in-water results shown here are part of what can be obtained. The **ATILA** code has already been tested by making comparison between numerical results and measurements. Therefore, it is an efficient tool for transducer designers that can save time and money.

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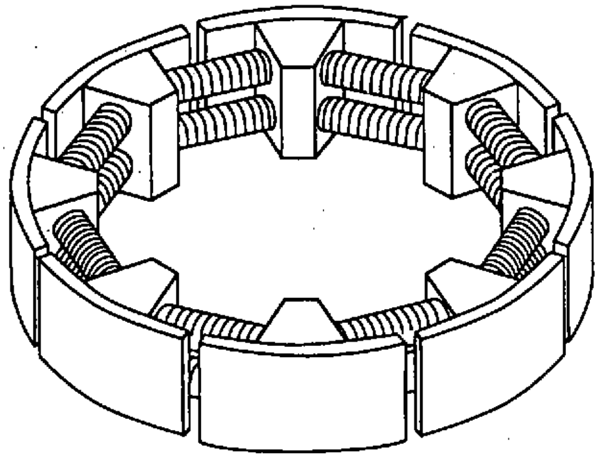

Figure 1: View of the basic polygonal ring.

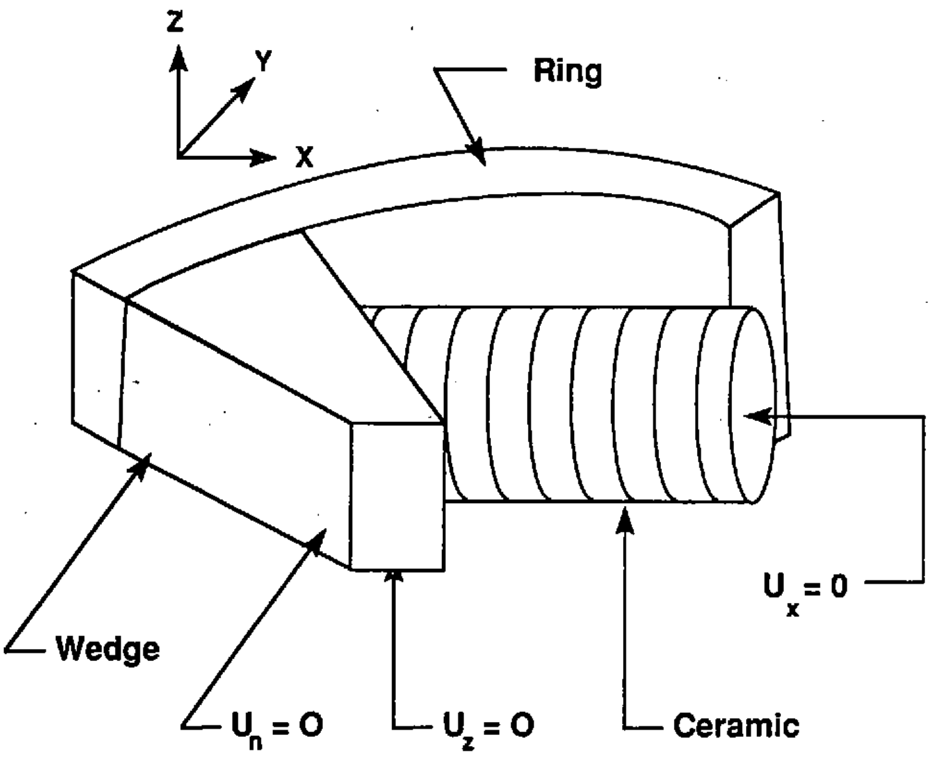

Figure 2 : Finite element model of the octagonal ring.

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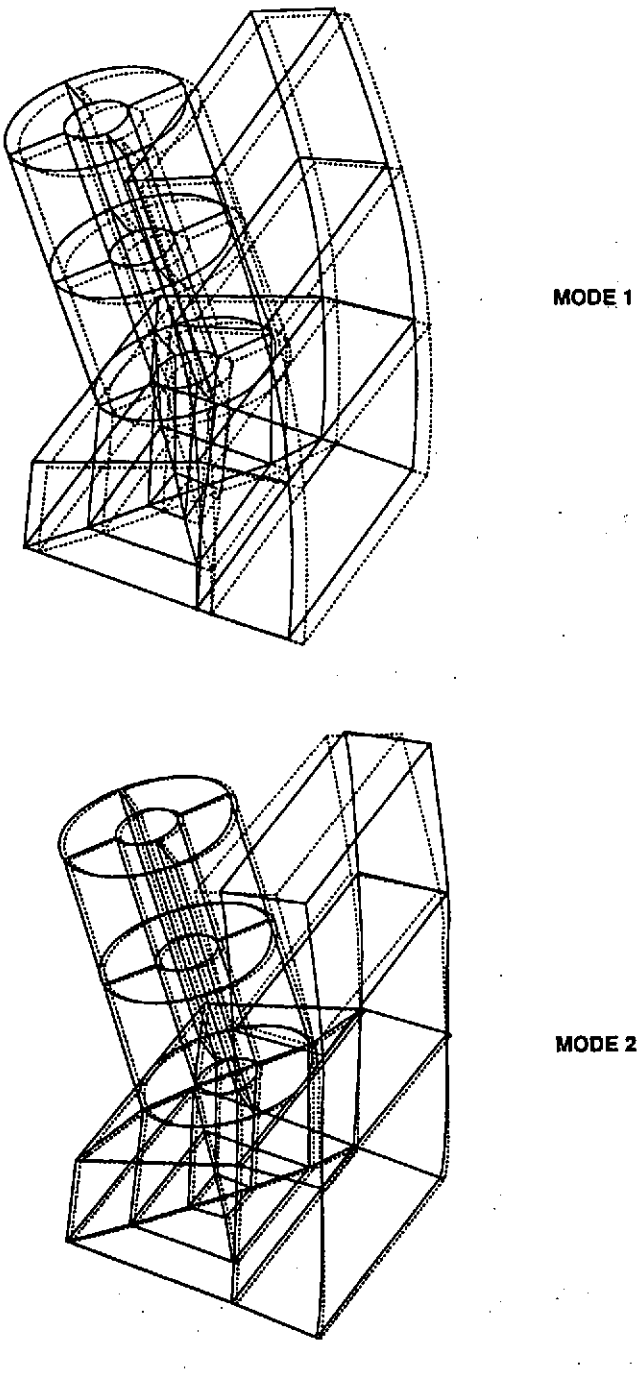

Figure 3 : The first two modes of the octagonal ring.

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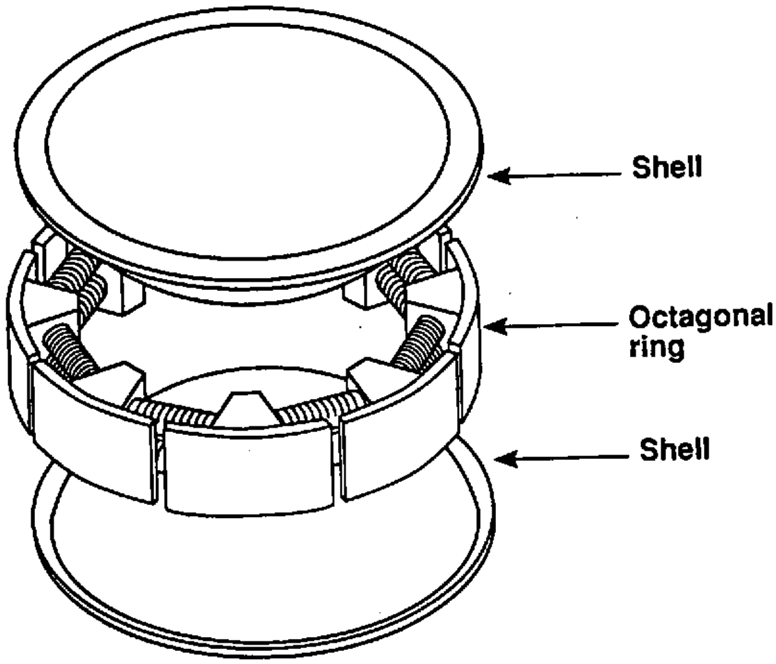

Figure 4 : Symmetrical flextentional

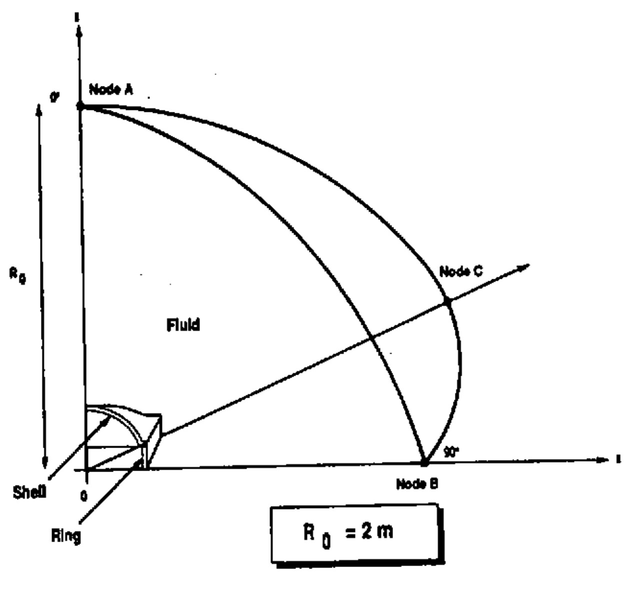

Figure 5 : Part of the fluid domain used for the computation

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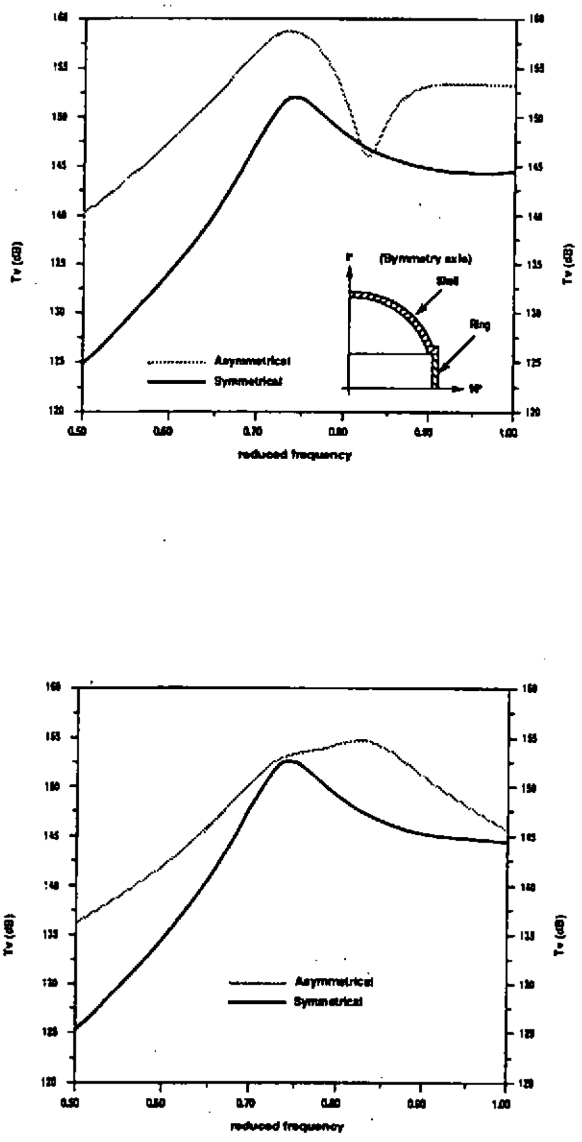

Figure 6 : Transmitting voltage response in the axial and radial directions.

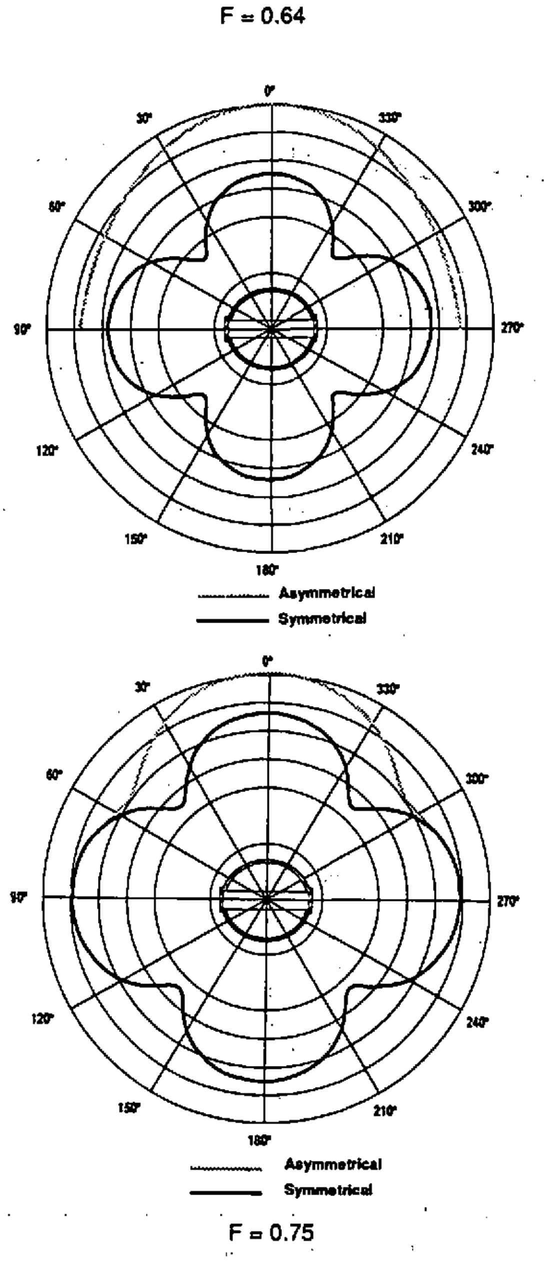

Figure 7 : Directivity patterns with normalisation

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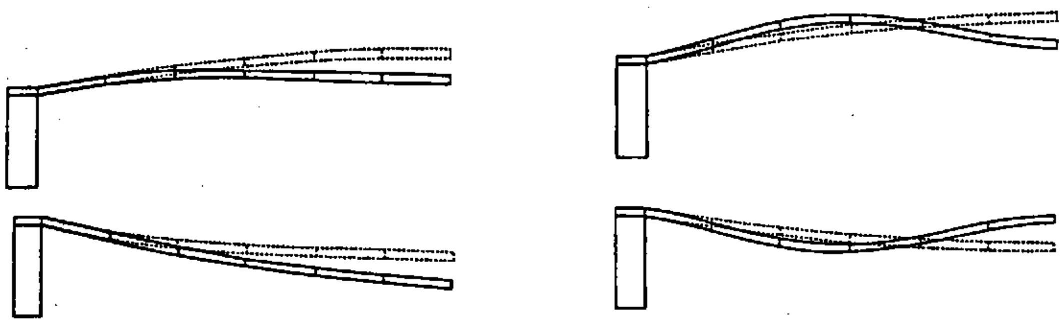

Figure 8 : Displacement fields of the convex and concave shells transducers.

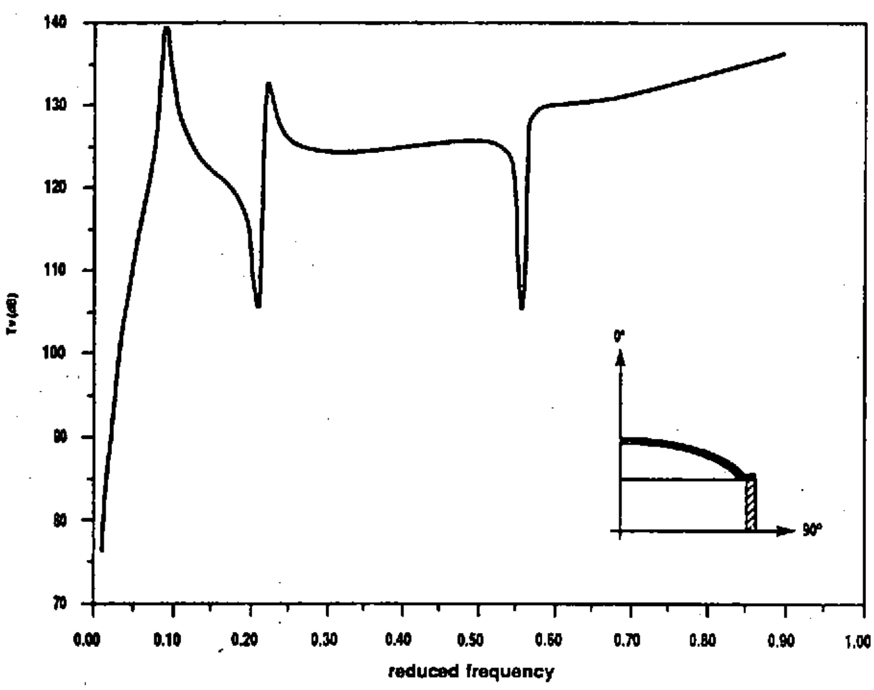

Figure 9 : Transmitting voltage response.