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Endfire Acoustic Radiation Reduction Technique for the HF MMPP

Richard A. G. Fleming

Defence R&D Canada – Atlantic

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TECHNICAL MEMORANDUM

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Abstract

The multi-mode pipe projector (MMPP) is a recently patented sonar projector capable of very wide bandwidth. The projector generates this bandwidth with an optimized approach to overlapping numerous drive motor and waveguide resonances. The high frequency MMPP (HF MMPP) was developed to operate over the 10-100 kHz band with a broadside transmitting voltage response of greater than 122 dB re 1μPa/Vrms @ 1m. This projector has recently been employed as a communications source over the 35-50 kHz band in the Networked Autonomous Littoral Surveillance (NetALS) program. The NetALS application involves orienting the HF MMPP vertically near the ocean bottom and using its horizontally-omnidirectional broadside acoustic radiation. However, since the endfire acoustic radiation of HF MMPP can be as much as 12 dB greater than the broadside acoustic radiation, there is increased likelihood of multipath distortion from endfire-generated surface and bottom reflections. A technique has been developed for diminishing endfire acoustic radiation which requires mounting a rigid air-cavity at a specific distance from each of the HF MMPP's endcaps. A prototype of the air-cavity attenuation technique reduced endfire TVR by more than 10 dB over the 35-50 kHz band.

Résumé

Le projecteur à tube multimode (MMPP) est un projecteur sonar récemment breveté qui peut fonctionner dans une très grande largeur de bande. Cette largeur de bande est obtenue selon une approche qui optimise le chevauchement de nombreuses résonances de moteurs d'entraînement et de guides d'ondes. Le MMPP haute fréquence (HF) a été développé pour fonctionner dans la bande de 10-100 kHz, avec une réponse en tension d'émission (TVR) de travers supérieure à 122 dB, rapportée à 1 μPa/V eff. à 1 m. Ce projecteur a récemment été employé comme source de communications dans la bande de 35-50 kHz, pour le programme de surveillance littorale autonome en réseau (NetALS). L'application NetALS nécessite l'orientation verticale du MMPP HF près du fond de l'océan ainsi que l'utilisation de son rayonnement acoustique de travers omnidirectionnel dans le plan horizontal. Toutefois, comme le rayonnement acoustique longitudinal du MMPP HF peut dépasser de 12 dB ou plus le rayonnement acoustique de travers, il existe une probabilité accrue de distorsion par trajets multiples en raison des réflexions longitudinales de surface et de fond. Afin de réduire le rayonnement acoustique longitudinal, on a mis au point une technique consistant à monter une cavité d'air rigide, à une distance déterminée de chacun des embouts du MMPP HF. Un prototype utilisant la technique d'atténuation par cavité d'air a permis de réduire la TVR longitudinale de plus de 10 dB dans la bande de 35-50 kHz.

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Executive summary

Introduction

Wideband sonar projectors are currently under development at DRDC Atlantic to provide multi-role projector solutions and permit production of spread-spectrum waveforms. These projectors could have a myriad of applications such as underwater communications, and torpedo counter-measures. The high frequency multi-mode projector (HF MMPP) provides wideband operation by means of numerous overlapping vibrational modes over the 10-100 kHz band. The Networked Autonomous Littoral Surveillance (NetALS) program has begun using the HF MMPP as a source for broadband communications in the 35-50 kHz band. The current NetALS application involves vertical orientation of the HF MMPP near the ocean bottom in a littoral environement and utilizes this projector's horizontally-omnidirectional broadside acoustic radiation. The HF MMPP has substantially more endfire acoustic radiation over much of its band of operation. This excess endfire radiation poses the risk of introducing significant bottom and surface reflection-induced multipath distortion and therefore may reduce the effectiveness of this communications scheme. An endfire acoustic radiation attenuation technique has been developed that entails mounting cylindrical, rigid, air-filled cavities a specific distance from the HF MMPP's endcaps.

Results

The HF MMPP's endfire transmitting voltage response (TVR) is no less than 140 dB re 1 μPa/Vrms @ 1m from 35 to 50 kHz. A prototype HF MMPP with attached air-cavity attenuators has an endfire TVR of on no more than 138 dB re 1 μPa/Vrms @ 1m from 35 to 50 kHz. The reduction in endfire radiation of discreet frequencies in this band was no less than 10 dB and at some frequencies of greater than 20 dB. The broadside TVR over the band was reduced less than 4 dB at any given frequency. With air-cavity attenuators attached, the HF MMPP's broadside TVR level is at least 4 dB greater than the endfire acoustic radiation over the 35-50 kHz band.

Significance

This new technique for attenuating the endfire acoustic radiation of the HF MMPP will enhance the effectiveness of this projector in communications applications where projector-induced multipath distortion would otherwise be a limiting factor.

Future Plans

The next step in the development of the HF MMPP endfire acoustic radiation attenuation technique is to begin varying spatial extent between the projector and air cavities and evaluating impacts on directivity pattern. This will also be followed with finite element modelling in order to create a fully-validated prediction tool for this technique. Pressure testing of the prototype air cavity will be carried out to ensure reliable operation at the required depth.

Fleming, R.A.G. 2006. Endfire Acoustic Radiation Reduction Technique for the HF MMPP. DRDC Atlantic TM 2006-261. Defence R&D Canada – Atlantic.

Sommaire

Introduction

Des projecteurs sonar à large bande sont en cours de développement à RDDC Atlantique afin de fournir des solutions multi-rôles permettant la production d'ondes à spectre étalé. Ces projecteurs pourraient trouver une myriade d'applications, par exemple dans les domaines des télécommunications sous-marines et des contre-mesures anti-torpilles. Le projecteur à tube multimode haute fréquence (MMPP HF) fonctionne en large bande et exploite le chevauchement de nombreux modes vibratoires dans la bande de 10-100 kHz. Dans le cadre du programme de surveillance littorale autonome en réseau (NetALS), on a commencé à utiliser le MMPP HF comme source de communications à large bande de 35 à 50 kHz. L'application NetALS actuelle nécessite l'orientation verticale du MMPP HF près du fond de l'océan dans un environnement littoral ainsi que l'utilisation de son rayonnement acoustique de travers omnidirectionnel dans le plan horizontal. Le MMPP HF produit un rayonnement acoustique longitudinal nettement plus élevé dans une grande partie de sa bande de fonctionnement. Ce rayonnement longitudinal excédentaire pose le risque d'engendrer une forte distorsion par trajets multiples liée aux réflexions sur le fond et la surface, et il peut donc réduire l'efficacité de ce système de communications. On a mis au point une technique d'atténuation du rayonnement acoustique longitudinal qui consiste à monter des cavités rigides et cylindriques remplies d'air, à une distance déterminée des embouts du MMPP HF.

Résultats

La réponse en tension d’émission (TVR) longitudinale du MMPP HF n'est pas inférieure à 140 dB, rapportée à 1 μPa/V eff. à 1 m, de 35 à 50 kHz. Un prototype de MMPP HF doté d'atténuateurs à cavité d'air offre une TVR longitudinale d'au plus 138 dB, rapportée à 1 μPa/V eff. à 1 m, de 35 à 50 kHz. La réduction du rayonnement longitudinal de fréquences discrètes dans cette bande n'était pas inférieure à 10 dB et, à certaines fréquences, elle était supérieure à 20 dB. La TVR de travers dans la bande a été réduite de moins de 4 dB, quelle que soit la fréquence. Lorsque des atténuateurs à cavité d'air sont utilisés, le niveau de la TVR de travers du MMPP HF dépasse d'au moins 4 dB le rayonnement acoustique longitudinal dans la bande de 35-50 kHz.

Portée

Appliquée au MMPP HF, cette nouvelle technique d'atténuation du rayonnement acoustique longitudinal améliorera l'efficacité de ce projecteur pour les communications, dans les cas où la distorsion par trajets multiples due au projecteur constituerait autrement un facteur limitatif.

Recherches futures

Durant la prochaine étape de développement de la technique d'atténuation appliquée au rayonnement acoustique longitudinal du MMPP HF, on commencera à faire varier l'étendue spatiale entre le projecteur et les cavités d'air ainsi qu'à évaluer l'incidence de ces variations sur le profil de directivité. Une modélisation par éléments finis permettra ensuite de créer un outil de prévision entièrement validé pour cette technique. La cavité d'air du prototype sera soumise à des essais de pression qui assureront la fiabilité du fonctionnement à la profondeur requise.

Fleming, R.A.G. 2006. Endfire Acoustic Radiation Reduction Technique for the HF MMPP (technique de réduction du rayonnement acoustique longitudinal pour MMPP HF). DRDC Atlantic TM 2006-261. Defence R&D Canada – Atlantic.

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1. Introduction

The Multi-mode Pipe Projector (MMPP) was invented at DRDC Atlantic and received a US patent in June 2003 (see Figure 1) [1]. The projector is designed to operate over a very wide frequency range by employing numerous overlapping vibrational modes. Unlike gas-backed flextensional designs [2], the mostly free-flooded MMPP's performance is insensitive to hydrostatic loading [3].

The high frequency version of the MMPP (HF MMPP) was optimized using the finite element code Model to Analyze the Vibration and Acoustic Radiation of Transducers (MAVART) operate over the 10-100 kHz band (see Fig. 1) [4]. The HF MMPP has a broadside transmitting voltage response (TVR) of greater than 122 dB re 1μPa/Vrms @ 1m and an endfire TVR of greater than 130 dB re 1μPa/Vrms @ 1m over much of its band (see Fig. 2 and Fig. 3). The high TVR band from 35 to 50 kHz is particularly attractive for underwater communications applications.

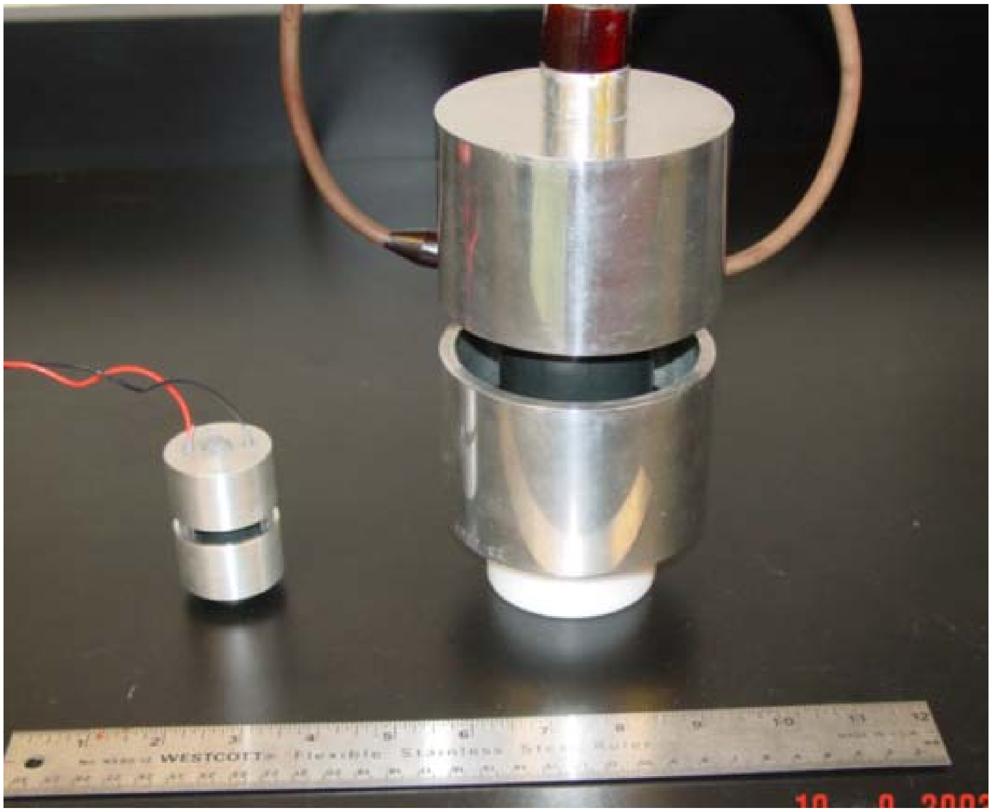

Figure 1. HF MMPP (left) and the mid-frequency MMPP (right).

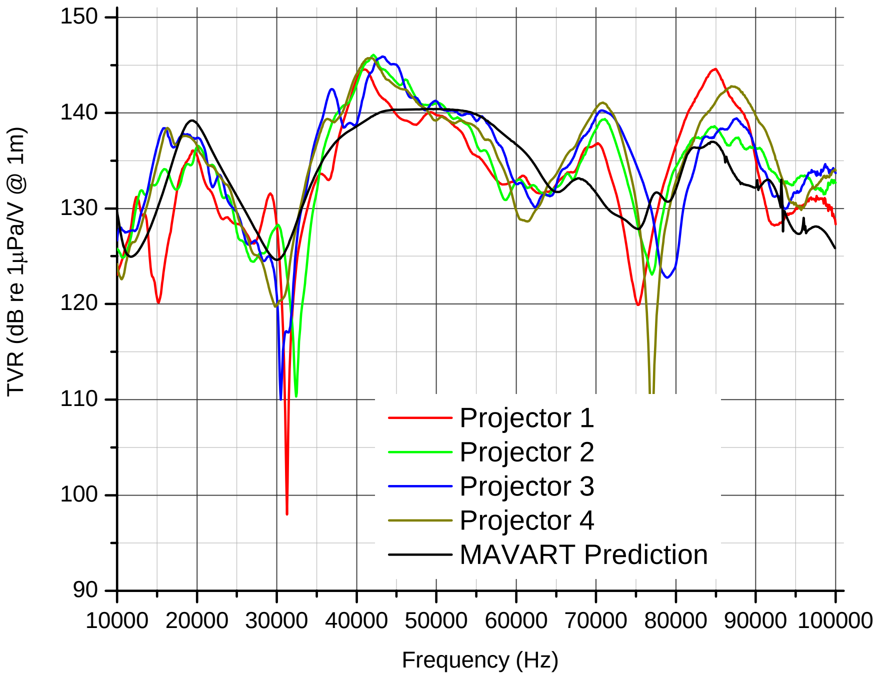

Figure 2. HF MMPP broadside TVR comparison between MAVART and measurement.

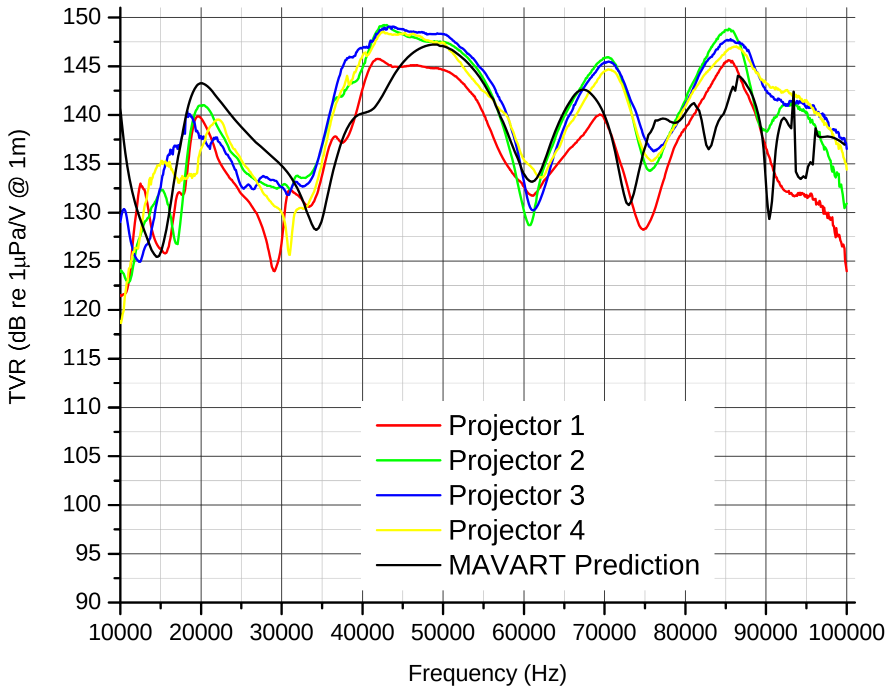

Figure 3. HF MMPP endfire TVR comparison between MAVART and measurement.

Recently, the HF MMPP has been integrated into the Networked Autonomous Littoral Surveillance (NetALS) system as a small, high-powered, broadband acoustic source for communications purposes (see Fig. 4) [5]. This application exploits the HF MMPP's horizontally-omnidirectional broadside acoustic radiation for communications in the 35-50 kHz band. It was noted that the HF MMPP's endfire acoustic radiation was more than 6 dB greater than the broadside acoustic radiation over this band. This excess endfire energy would be directed toward the surface and the nearby bottom increasing the likelihood of introducing multipath distortion into the communications channel.

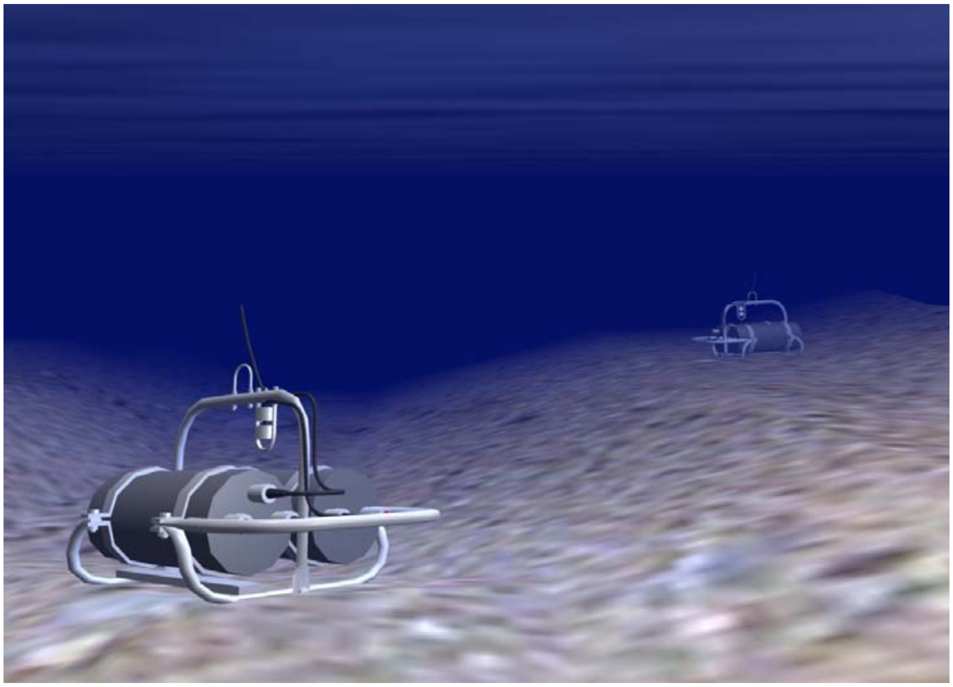

Figure 4. HF MMPP and related electronics in NetALS application.

It was posited that by adding a pressure-release surface inline with the endfire radiation, the level of unwanted acoustic radiation could be reduced without severely affecting the broadside response. This pressure release surface would take the form of a rigid watertight cylinder resiliently mounted to the ends of the HF MMPP. Another possible solution would be to position the HF MMPP between very stiff and massive plates but this solution would severely limit the utility of this small projector.

2. Initial finite element air-cavity modelling

Preliminary investigation into the efficacy of adding a pressure release air-cavity inline with the endcaps of the HF MMPP involved simply replacing water elements with air elements in a rotationally and axially symmetric finite element model of the HF MMPP (see Fig. 5).

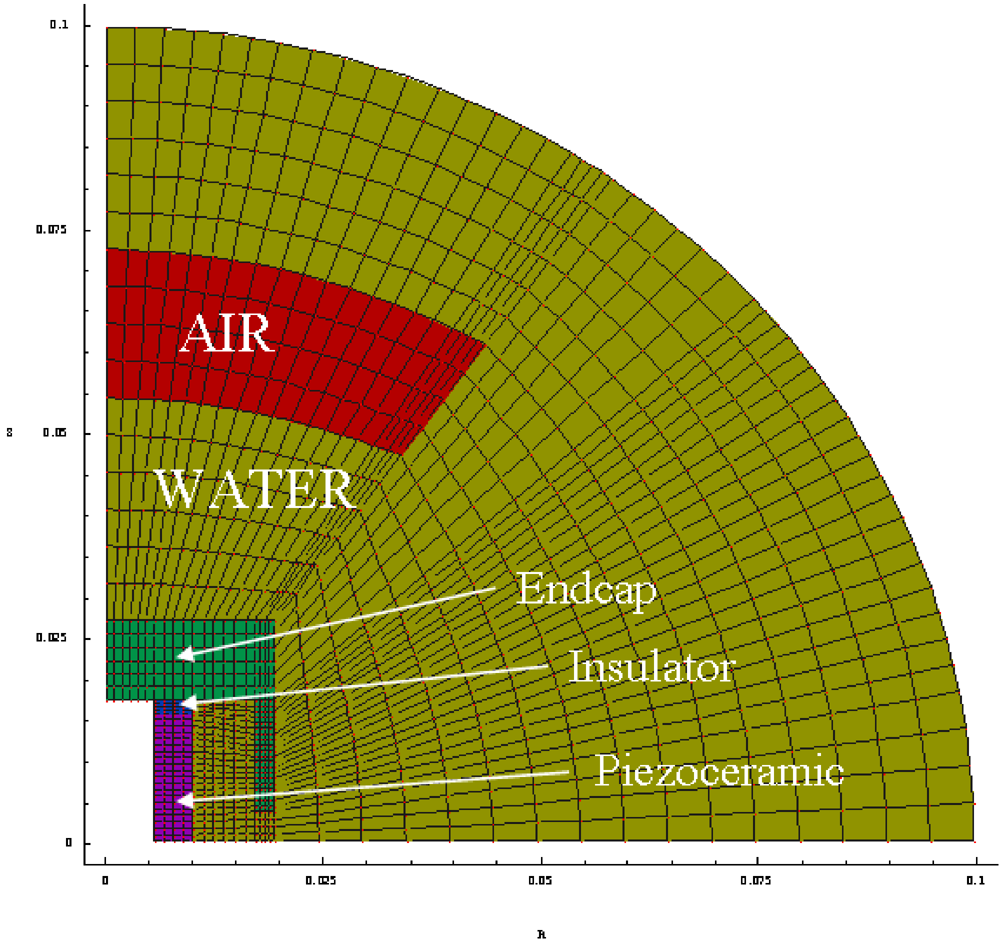

Figure 5. HF MMPP 1st quadrant model with segment of water changed to air.

Finite element processing of this model with MAVART revealed a marked drop in endfire TVR (see Fig 6.) with only slight reduction in broadside TVR (see Fig. 7). The reduction in endfire acoustic radiation was very evident in the 35-50 kHz band which was fortuitous in determining both the potential for success of this technique for the NetALS application and the rough dimensions required for a prototype air-cavity.

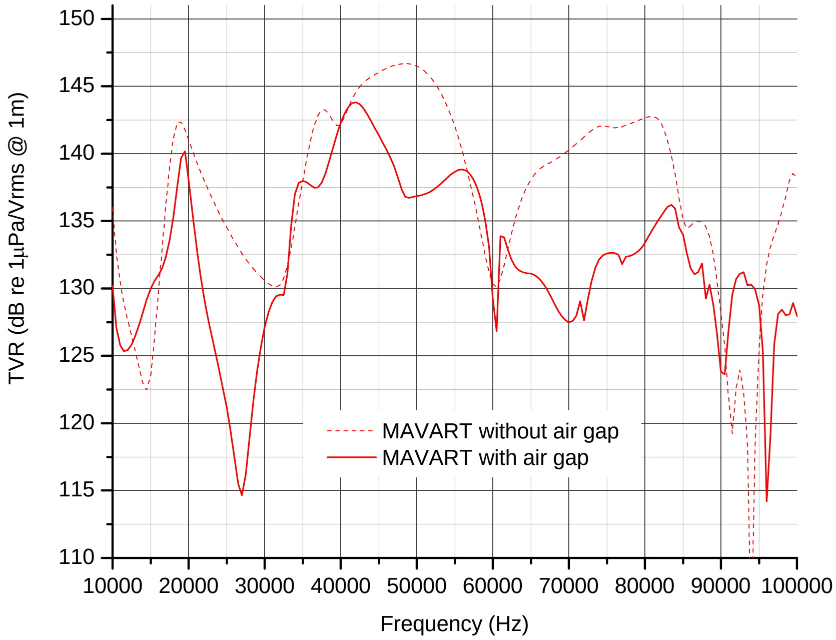

Figure 6. Endfire TVR of HF MMPP with air segment inline with endcap.

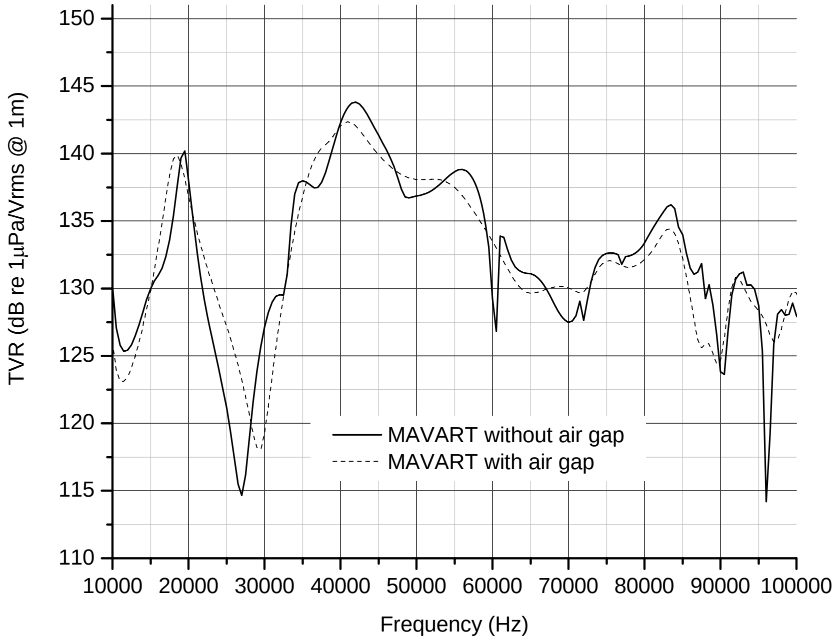

Figure 7. HF MMPP broadside TVR with air segment inline with endcap.

3. Prototype rigid air-cavity

A pair of prototype HF MMPP air-cavity attenuators was constructed based on the approximate dimensions from the initial finite element modelling. These attenuators were constructed from PVC Schedule 40 pipe and acrylic plate stock as these materials nearly match the bulk modulus of water (as compared to metal) and thus retain much of the physics air-cavity model. The PVC pipe is 8.93 cm outside diameter (OD) with 6.1 mm wall thickness. The acrylic sheet is 5.8 mm thick and cut into discs such they matched the OD of the PVC pipe. This ensures that hydrostatic pressure will compress the ensuing joints. The pipe sections of the air-cavities are 1.54 cm long and bonded to the acrylic discs with Hysol 9460 epoxy. Pieces of adhesive-lined heat shrinkable tubing were bonded to the outside of the assembled rigid air-cavities for additional waterproofing.

A 5/16” nylon nut was epoxied to the center of each of the assembled air-cavities. A 5/16” threaded nylon rod approximately 2 cm long formed the HF MMPP to air-cavity strength member. A 5-40 threaded hole was tapped into the nylon rod for acceptance of the HF MMPP’s prestress rod. The assembled HF MMPP with rigid air-cavities can be seen in Figure 8.

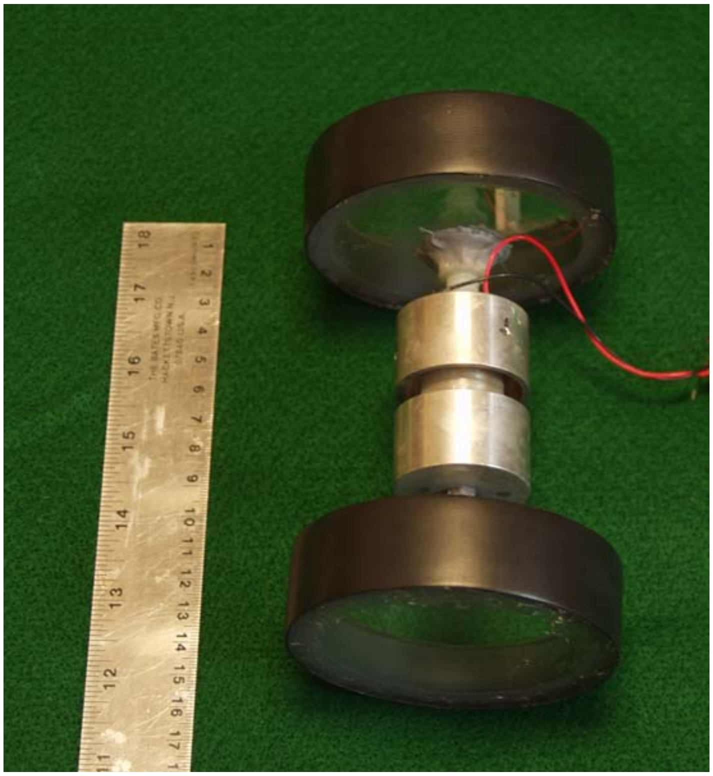

Figure 8. HF MMPP with prototype rigid air-cavity attenuators.

TVR testing on the rigid air-cavity attenuator-equipped HF MMPP was carried out in DRDC Atlantic’s acoustic calibration tank using the TRANSCAL calibration suite. Results showed that the endfire acoustic radiation was dramatically decreased with some reduction in broadside output (see Figure 9). The unmodified HF MMPP has an endfire transmitting voltage response (TVR) no less than 140 dB re 1 μPa/Vrms @ 1m from 35 to 50 kHz with peak values near 150 dB. The prototype HF MMPP with attached air-cavity attenuators has an endfire TVR of on no more than 138 dB re 1 μPa/Vrms @ 1m from 35 to 50 kHz with considerable attenuation at 42 and 46 kHz. The reduction in endfire radiation of discreet frequencies in this band was no less than 10 dB across the band and at some frequencies of greater than 20 dB. The broadside TVR over the band was reduced by no more than 4 dB at any given frequency. With air-cavity attenuators attached, the HF MMPP's broadside TVR level is no less than 4 dB greater than the endfire acoustic radiation over the 35-50 kHz band.

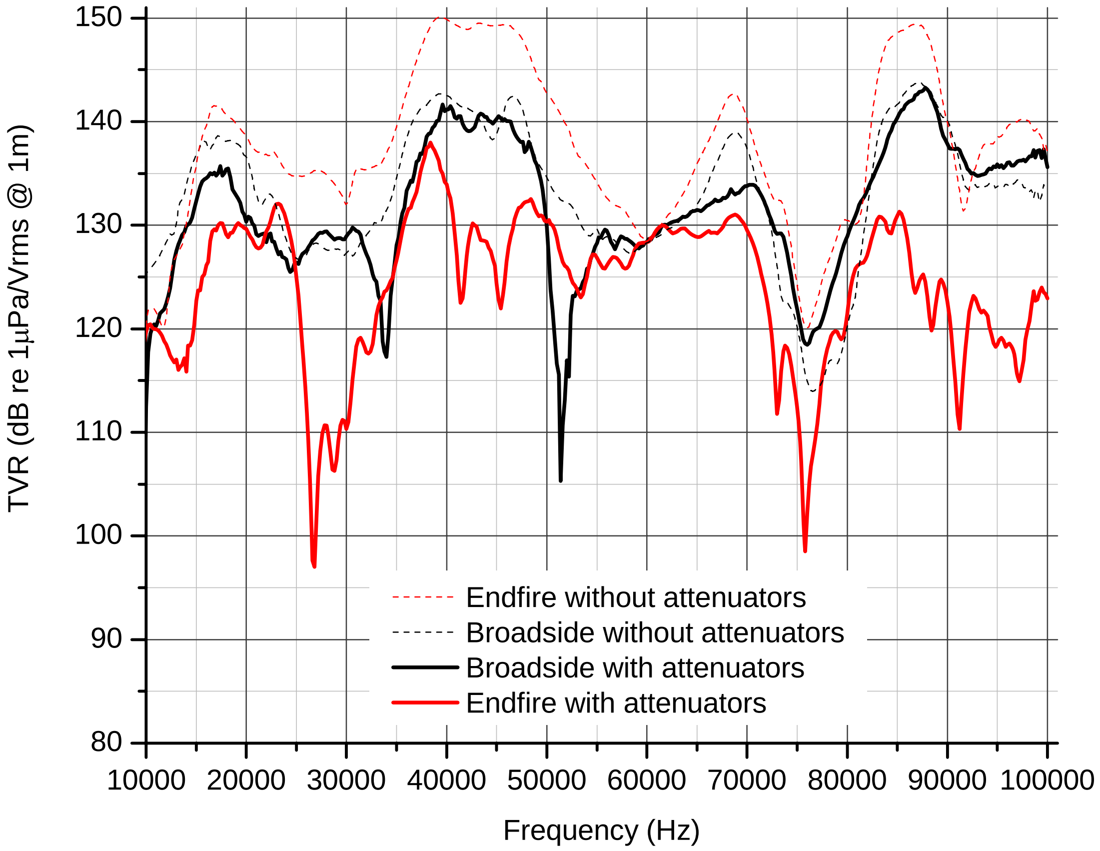

Figure 9. Comparison of HF MMPP TVR with and without air-cavity attenuators.

4. Rigid air-cavity attenuator finite element modelling

A finite element model of the rigid air-cavity attenuator was built so as to have a tool for later optimization of the air-cavity with respect to its size, constituent materials and location with respect to the HF MMPP's endcaps (see Fig. 10). This model is parametric so changes to the projector size as well of the properties of the air-cavity can be readily changed.

Initial finite element analysis has shown TVR behaviour similar to that of the prototype. TVR level agreement between the model and the measurements is reasonable in that the finite element results reflect the measurement's lowered endfire acoustic radiation and mirror some of the resonance behaviour of the system (see Fig. 11). The broadside finite element results are in coarse agreement at low frequency but fail to reveal some nulls seen in the measurement. More study is necessary to fully validate this model in conjuction fitting of damping constants for the polymers used in the construction of the rigid air-cavities. Figures 13 and 14 show some of the predicted variability expected when distance between the midline of HF MMPP and the bottom of the rigid air-cavity distance is varied. Note that the broadside TVR (Fig. 14) is relatively insensitive to change while the endfire TVR (Fig. 13) is quite variable. Figure 15 shows MAVART predicted beam patterns over the NetALS band of interest. In all cases, the broadside response is predominant.

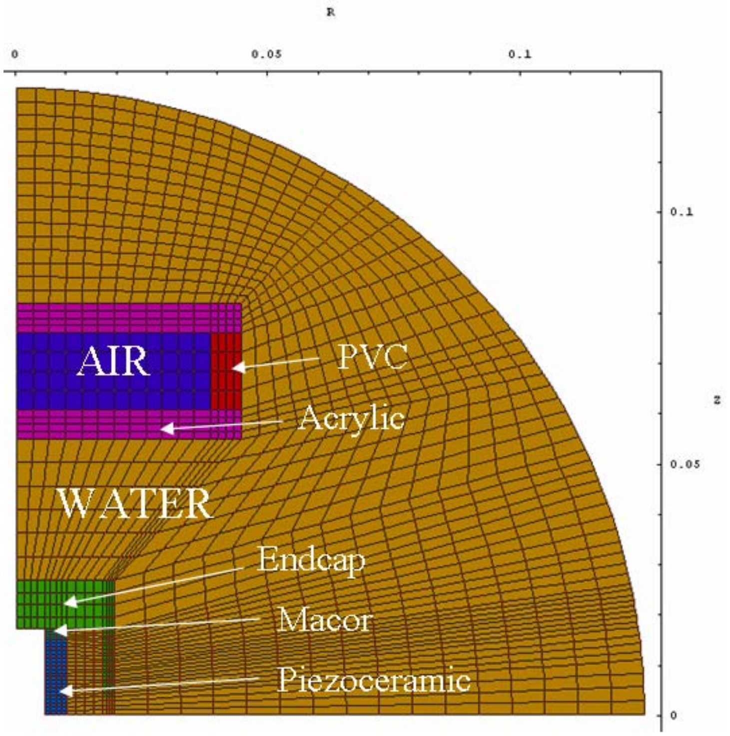

Figure 10. 1st quadrant 2D model of HF MMPP and rigid air-cavity attenuator.

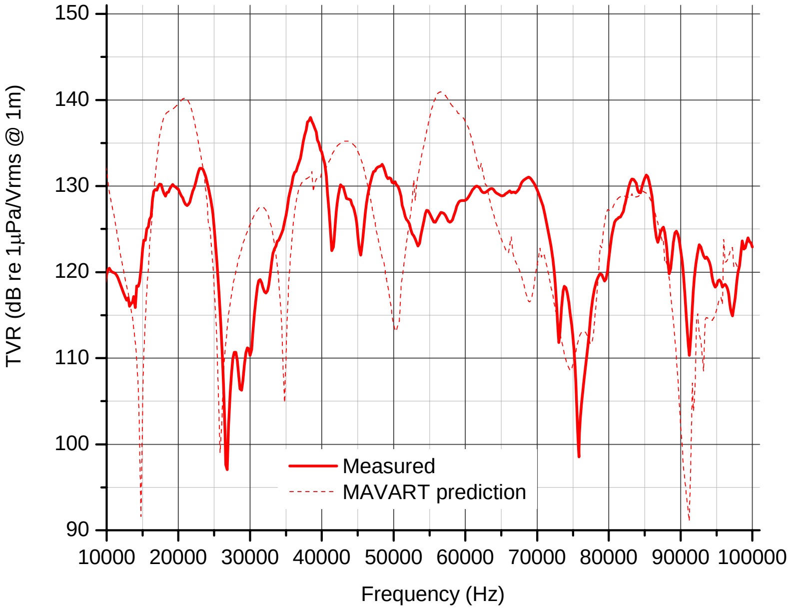

Figure 11. MAVART versus measurement comparison of HF MMPP endfire TVR with rigid air-cavity attenuators.

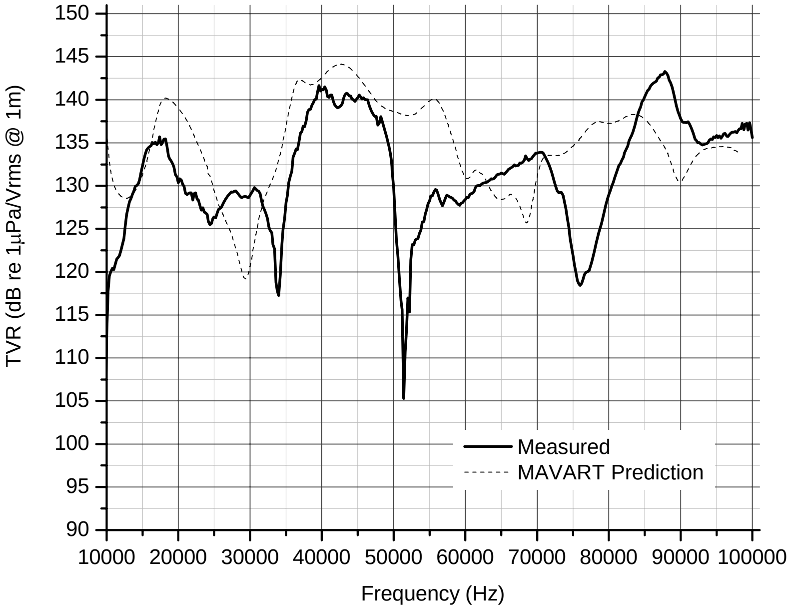

Figure 12. MAVART versus measurement comparison of HF MMPP broadside TVR with rigid air-cavity attenuators.

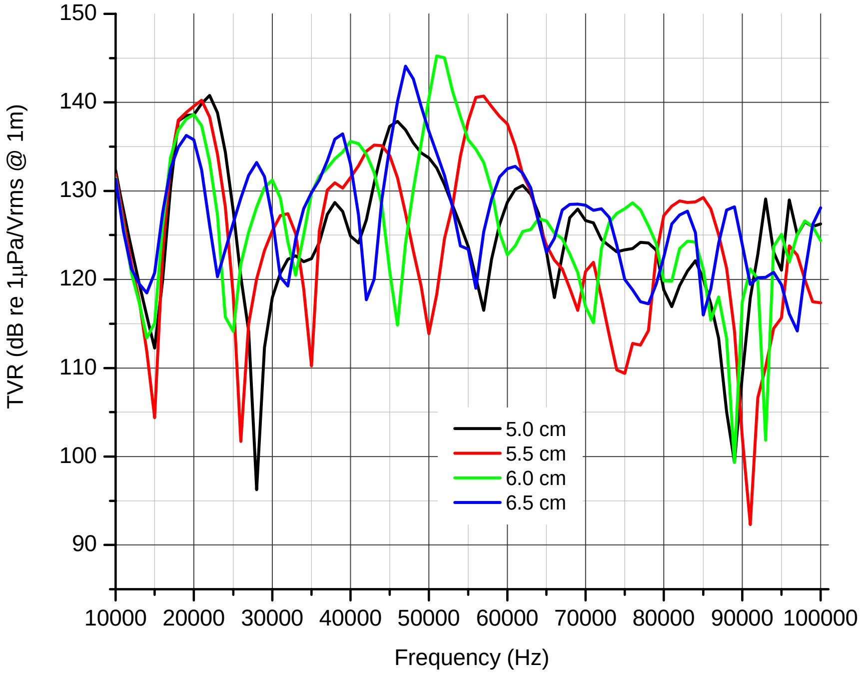

Figure 13. MAVART-prediction of endfire TVR with changes in distance between center of HF MMPP and bottom of rigid air-cavity.

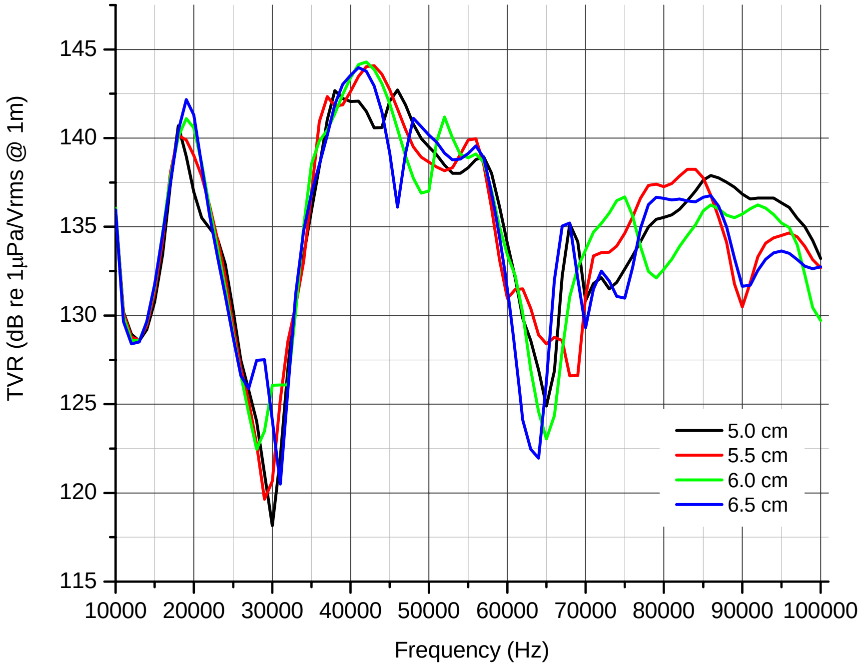

Figure 14. MAVART-prediction of broadside TVR with changes in distance between center of HF MMPP and bottom of rigid air-cavity.

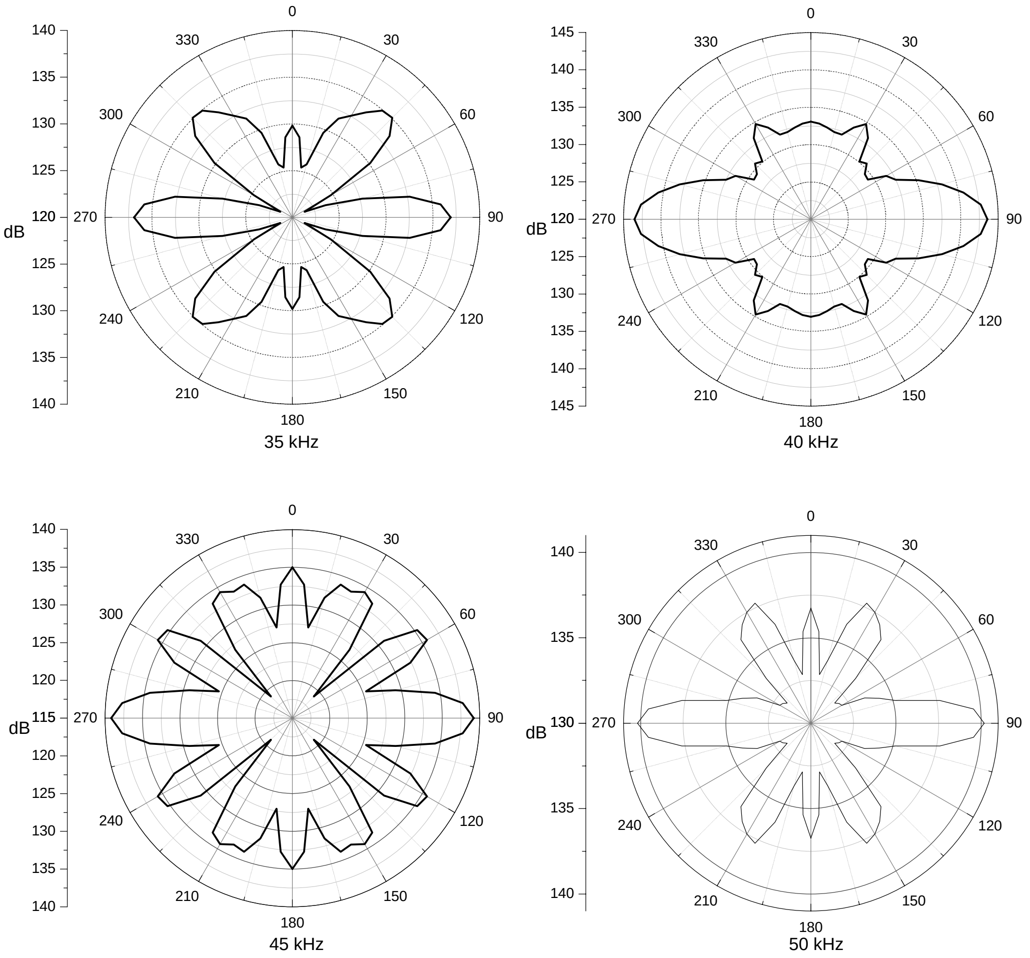

Figure 15. MAVART predicted beam patterns for 35, 40, 45 and 50 kHz (0 degrees is endfire axis).

5. Discussion

The HF MMPP is a broadband depth-insensitive acoustic projector with a broadside TVR of greater than 122 dB re 1μPa/Vrms @ 1m and an endfire TVR of greater than 130 dB re 1μPa/Vrms @ 1m over the 10-100 kHz frequency band. Earlier work has shown that the endfire direction has the highest response with respect to all other angles with the HF MMPP [6]. The excess endfire and high angle acoustic radiation can be detrimental to underwater communications applications such as NetALS where bottom and surface reflections can lead to multipath distortion. These conditions include those where transmission loss over a reflection path length would be insufficient to reduce that path's signal level to below that of the direct path. Provided that the direct path contains more energy than the reflected path and the signal duration is short or the direct path contains significantly more energy than any other path, multipath effects can be minimized.

In the case of the HF MMPP, without any endfire and high angle output level correction, it can be concluded that multipath distortion would be significant especially when the HF MMPP is employed either near the seabed and or where the direct path length is much longer than the total water depth. In these situations, even after reflection, reflected path energy could still be higher than that in the direct path.

Using the described method for endfire acoustic radiation control must take into account the frequency band of operation and geometric aspects of the application of the HF MMPP.

6. Conclusion

This simple solution may make it possible to enhance the efficacy of the HF MMPP in regimes where multipath distortion would otherwise limit the coherence of a communications channel. These regimes would include those where transmission loss over a reflection path length would be insufficient to reduce that path's signal level to below that of the direct path.

The described rigid air-cavity attenuation technique is shown by both finite element modeling and measurements to reduce endfire radiation by at least 10 dB over much of the HF MMPP's frequency band of operation. MAVART modeling has indicated that with the rigid-air cavities, the broadside response of the HF MMPP predominates over all other response angles.

Ongoing MAVART modeling of the rigid air-cavity technique will yield a validated tool for rapidly designing endfire rigid air-cavities for given frequencies or MMPP dimensions. Preliminary modeling shows little broadside sensitivity to rigid air-cavity placement while endfire response varies greatly.

Testing of the HF MMPP with and without the rigid air-cavities in conjunction with finite element modeling will reveal the full impact of this attenuation technique on underwater communications.

6. References

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List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
DRDC	Defence Research and Development Canada
MMPP	Multi-mode pipe projector
HF MMPP	high frequency multi-mode pipe projector
MAVART	Model to analyze the vibration and acoustic radiation of transducers
Hz	hertz
TVR	transmitting voltage response
dB	decibel
NetALS	Networked Autonomous Littoral Surveillance

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(U) The multi-mode pipe projector (MMPP) is a recently patented sonar projector capable of very wide bandwidth. The projector generates this bandwidth with an optimized approach to overlapping numerous drive motor and waveguide resonances. The high frequency MMPP (HF MMPP) was developed to operate over the 10-100 kHz band with a broadside transmitting voltage response of greater than 122 dB re 1μPa/Vrms @ 1m. This projector has recently been employed as a communications source over the 35-50 kHz band in the Networked Autonomous Littoral Surveillance (NetALS) program. The NetALS application involves orienting the HF MMPP vertically near the ocean bottom and using its horizontally-omnidirectional broadside acoustic radiation. However, since the endfire acoustic radiation of HF MMPP can be as much as 12 dB greater than the broadside acoustic radiation, there is increased likelihood of multipath distortion from endfire-generated surface and bottom reflections. A technique has been developed for diminishing endfire acoustic radiation which requires mounting a rigid air-cavity at a specific distance from each of the HF MMPP's endcaps. A prototype of the air-cavity attenuation technique reduced endfire TVR by more than 10 dB over the 35-50 kHz band.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title).

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