Potential of Steel-Fibre-Reinforced Concrete to increase RFI mitigation of antenna foundations

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***Abstract*—The preservation of a radio quiet site for both ASKAP and SKA telescopes relies on maintaining EMC compliance of all equipment. A potential source of radio frequency interference (RFI) is from leakage of RF signals from equipment housed within the antenna structure (most notably the pedestal electronics and power systems) through the foundations.**

In this paper we summarise our investigation into the additional RFI shielding properties of concrete doped with a range of steel-fibre, comparing the results to standard (un-doped) concrete. We describe our non-destructive test method which has no limitation on the specimen size and removes the need of preparing the high precision dimensions of specimen.

We find that the concrete doped with 100 kg/m3 of steel fibre offers significant additional shielding effectiveness at the frequencies measured; this is at an attractive cost when compared to alternative commercial products also on the market.

***Keywords* – Shielding Effectiveness, Steel-Fibre-Reinforced Concrete, non-destructive test method.**

I. Introduction

Australia and Southern Africa are selected to host the Square Kilometre Array (SKA) radio telescope. Both countries have identified SKA core sites and have stringent EMC/RFI standards to which all activity has to adhere, as in [1].

The cost of dealing with self-generated RFI – that generated by the telescope and instrumentation, is extremely expensive both in additional processing costs and the (unquantifiable value) of unusable astronomy data. These challenges have led us to consider a range of aspects of dish antenna design, particularly in building the new 36-dish antenna array radio telescope - Australian Square Kilometre Array Pathfinder (ASKAP). Each of ASKAP's 12m dish antennas are mounted on a 2.4m diameter cylindrical steel tower (pedestal), bolted to a 6m x 6m x 0.8m concrete foundation.

There is a potential RFI leakage path from the instrumentation housed within the antenna structure via transmission through the concrete foundation; this is also complicated by the potential for multiple reflections off the steel reinforcing bars embedded within the concrete such that the RFI could emerge anywhere within the vicinity of the dish antenna structure. .

For ASKAP, screening this potential leakage path involves installing an RFI-tight floor, with a continuous linkage from the pedestal structure and across the floor area. In reality this RFI-tight floor can only be installed after the antenna is built and the time/labour costs are high at the remote site. A better solution would be to improve the overall dish antenna design so that some of this shielding was in-built, and also to increase the shielding effectiveness of the foundations themselves.

This paper investigates one possible option for increasing the shielding properties of antenna foundations using admixtures of steel fibres within the concrete. There are also commercial products available claiming to have similar properties. Whilst we find that there is scope to improve such foundations we did not adopt this technique for ASKAP as we are confident that our antennas are well shielded as built.

II. The Material Under Test

Steel-fibre reinforced concrete is produced by simply adding bulk quantities of pre-packaged steel fibres to concrete as it is being mixed, with no other change to the process or equipment needed.

Steel-fibre reinforced concrete is becoming more widely used in construction due to its better resistance to fine cracking and to crack propagation with respect to plain concrete reinforced with conventional rebar. However it is not sufficient to be used as an EMI shielding or absorbing material.

Although there is some research in the literature on the RFI shielding properties of various materials, the characteristics of steel fibre reinforced concrete have not been thoroughly investigated [2, 3].

For our testing purposes, four concrete slabs (see Fig. 1) were prepared. They have identical size and construction, 1000 mm × 1000 mm × 150 mm, with one layer of N24

(24mm) steel reinforcing bars on an orthogonal grid at 200mm spacing. This is representative of the upper 150mm thickness of the ASKAP antenna foundation.

Fig. 1 Test samples – four concrete slabs with different fraction of steel fibre

Each slab had a different amount of steel fibre:

1) Concrete slab with a standard re-bar and no steel fibre

2) Concrete slab with 20kg/m3 steel fibre

3) Concrete slab with 60kg/m3 steel fibre

4) Concrete slab with 100kg/m3 steel fibre

The steel fibres were mixed with the concrete before it was poured to make the slabs. No special care beyond conventional mixing was needed to ensure uniform density and a random orientation of the steel fibres to obtain the uniform and isotropic strength properties of the slabs. The slabs were cured for more than a month to eliminate the effect of moisture before testing.

III TEST MEASUREMENT PROCEDURE

Traditional methods for evaluating the shielding effectiveness (SE) are defined in MIL-STD 285 [4] and IEEE-STD-299 [5]. Those methods based on the classic setup by placing a transmitting antenna outside of a shielded enclosure while a receiving antenna is placed inside the shielded enclosure. Those methods require fabricating a special window for the test sample. It is easy for a small sample. However, this approach can be expensive, complex process and time consuming for the large sample.

A number of modified methods have been proposed for the measurement of SE. For example, the commonly-used technique for evaluating SE is ASTM (American Society of Test and Materials) D4935 method [6]. This method applies to the measurement of SE of planar materials under normal incidence, far-field, plane-wave conditions. The test fixture is an enlarged circular coaxial transmission line, which has flanges for inserting the disk- shaped specimen. The disadvantage of this method is that it is only suitable for small samples. A few researchers have proposed other measurement methods, such as 3mm wave radar reflectance measurer [3] and coaxial cable method [7] - [8]. All of these methods have certain limitation on specimen size thus specimen preparation is necessary which is time-consuming and potentially unrepresentative.

To address these problems, we present a much simpler alternative approach. We determine that the concrete slab can be tested via the WR650 waveguide horn measurement method. The open-ended waveguide technique [9] has been developed which have the potential to be applied for the non-destructive measurement of shielding effectiveness. Our approach is similar to the open-ended waveguide technique but has more transmission power. This method is non-destructive, no limitation for the sample size and does not require specimen preparation.

Our tests were performed in our anechoic chamber to reduce the reflections and insulate from exterior sources of noise. The internal dimensions of the chamber are 8m x 6m x 4m. The testing system includes an Agilent E8257D PSG Analog signal generator, two PENN WR650 waveguide horns used as transmitting and receiver antennas respectively, and an Agilent E4407B spectrum analyser.

A specially designed wooden support was used to hold the test sample vertically (straight up and down). The test sample was sandwiched between two WR650 waveguide horns. The horns were closely contacted towards the centre of the concrete. Due to the imperfection of the concrete surface, we have to place absorbers around horns to reduce resonant and absorbing edge-diffracted energy (refer to Fig. 2 for the test setup).

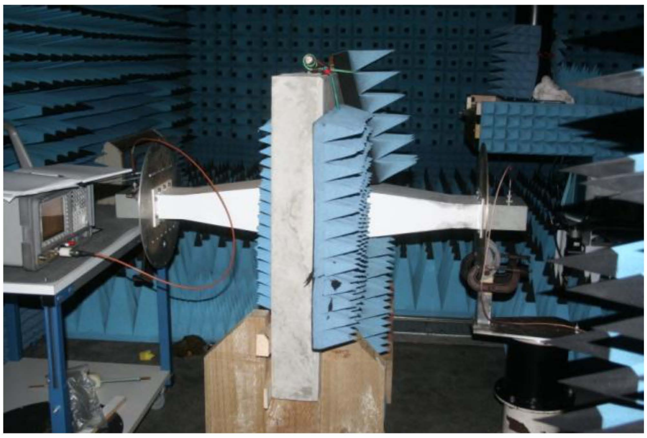

Fig. 2 Measurement setup in an anechoic chamber

The test sample was placed in the centre plane of the WR650 horns. The input of the WR650 adaptors was connected to the Agilent E8257D signal generator and output to the Agilent E4407B spectrum analyser. The frequency range of WR650 waveguide horn is 1.12 to 1.7 GHz. The cut off frequency is 0.908GHz. The frequencies were swept from 1 to 1.9 GHz.

IV Results

The EMI attenuation from a concrete slab depends on three factors. The first is the reflection of the wave from the concrete slab. The second is the absorption of the wave as it passes through the concrete slab. The third is due to the re-reflections, i.e. the multiple reflections of the waves at various surfaces or interfaces within the concrete slab.

Before measuring the shielding effectiveness of each of the concrete slabs, we calibrate the system with the two WR650 waveguide horns 150mm apart to provide an air path reference value. The results are recorded as the reference value from which the shielding effectiveness is derived. Then a concrete slab is placed between the centre of horns. The reference value is compared to that value acquired with the concrete slab. The difference between these is the shielding effectiveness.

With the sample present, the electromagnetic waves will be partially reflected, and partly transmitted across the boundary and into the material. The effectiveness of the shielding is the sum total of these two effects, plus a correction factor to account for reflections from the back surfaces of the shielding.

The test conditions for each of measurements are same, so the correction factor is unchanged. The results reflect the true value of the attenuation. In addition, the same test condition also ensures the measurement accuracy and minimizing uncertainty.

The measurement results of the concrete slabs with different fraction of steel fibre shielding are shown in Fig. 3.

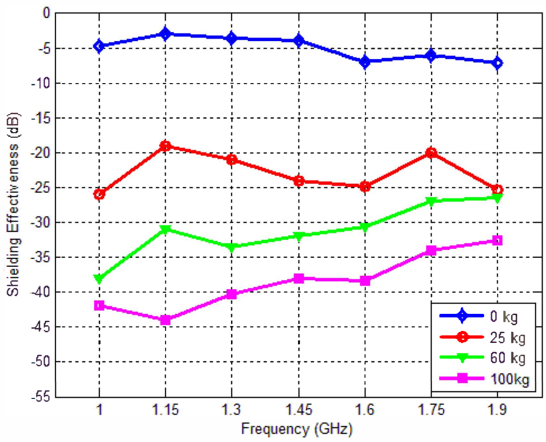

Fig. 3 Plot of the attenuation vs. frequency. The blue curves correspond to the attenuation of plain concrete slab; The red, green, magenta curves correspond to the attenuation of the concrete slab containing the steel fibre of 25 kg, 60kg, and 100kg respectively.

As can be seen from Fig. 3, the shielding effectiveness of plain concrete with rebar is low (less than 5 dB across the band). The attenuation increases with the steel-fibre volume fraction. There are also attenuation changes with frequency.

Up to 38dB attenuation can be achieved with 100kg steel fibre at ~1GHz. We notice that 25kg curve has different trend compare to 60kg and 100kg, this may caused by the uneven distribution of the steel fibre in the concrete. On the whole the more steel fibre, the better attenuation can be achieved.

V Application

The foundations for the ASKAP antennas for which this material was investigated consist of reinforced concrete slabs 6m x 6m x minimum 800mm deep, cast with an integral "upstand" in the centre of the top surface for the antenna interface. The upstand section was 3m in diameter x 150mm high and contains about 1 cubic metre of concrete. See Fig. 4.

If steel fibre reinforced concrete had been adopted for ASKAP, it would have been necessary to use this concrete mix in the upstand area only, rather than through the entire mass of the foundation.

At a mix ratio of 100kg/m3 steel fibre in this section of concrete, the cost of steel fibre would be less than $400, based on the cost of fibre published by a manufacturer in an on-line quoting tool [10].

The formwork design for this foundation used an upper ring section to contain the concrete for the upstand, so applying steel fibre reinforced concrete to this section only would be a simple process of pouring the last part from a different mixing vehicle, after filling the main bulk of the foundation with conventional non-fibre concrete.

No other special processes would be required and the slab could be levelled and finished by the same methods as any conventional concrete mix, and the portion of steel-fibre concrete would exhibit the same structural properties as the main bulk of the foundation.

A number of commercial "conductive concrete" mixtures were also investigated for use in the ASKAP antenna foundations by comparing cost and published properties. Typically these materials would have resulted in significantly higher costs or degradation in structural properties compared to steel fibre reinforced concrete.

Fig. 4 An ASKAP antenna pedestal being lowered onto the foundation. The "upstand" in the centre of the foundation is 3m diameter x 150mm high

VI Conclusions

We have determined a simple test method for the measurement of the shielding effectiveness of bulk materials and validate the results in comparison with past results using WR650 waveguide enclosures. We determine that the direct transmission method described here is equivalent to methods which use a waveguide enclosure as our two horns mimic the waveguide setup by being in close and direct contact. This technique thus has application to large-scale samples where destructive testing is not feasible, and/or you wish to check the properties over a large-scale piece of material.

We find that the RF insulating performance of concrete doped with increasing amounts of steel fibres is significant and that a shielding effectiveness of more than 38 dB around 1GHz and 26 dB around 1.9 GHz is possible with a 3% admixture.

The measurement results demonstrate that the steel fibre reinforced concrete has excellent electromagnetic wave shielding effectiveness. The steel rebar will contribute to the shielding but this effect is small compared to that added by the steel fibre.

Application of this type of concrete to key areas of an antenna foundation for improved shielding presents a very small cost increase in materials with no significant impact on processing on the construction site.

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