HIGHRISE BUILDING RERADIATION AND DETUNING AT MF

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Abstract

An evaluation of the reradiation from highrise buildings in the MF broadcast band is presented. Scattered field measurements were made at MF on buildings of the order of one quarter wavelength in electrical height and at UHF on scale models. A computational model incorporating the effects of lossy ground and building materials was developed using moment-method techniques. Reduction of scattering is demonstrated, both for models and a full-scale building, using simple wire detuning stubs to modify the induced RF currents. The current distributions resulting in the decrease of scattering are described for a vertical stub like those used in power line detuning, and for two related new designs, a rooftop stub and the "umbrella" stub. The latter is shown to be the most effective, yielding scattered field reductions of the order of 6dB in full-scale tests.

Introduction

Reradiation of medium frequency broadcast signals from large man-made structures has been increasing in recent years. With the spread of urban population, the associated conducting structures such as power lines, towers, smoke stacks and highrise buildings are frequently built near existing broadcast transmitting sites. In addition, new antenna sites may, in some cases, be located near such reradiators because of coverage area considerations or land use restrictions. If the structures have dimensions of the order of a wavelength the scattered field arising from the induced RF currents can be strong enough to cause significant distortion of the radiation pattern of a nearby MF transmitting antenna.

Distortion of an omnidirectional pattern is normally in the form of a number of maxima and minima superimposed on the normal radiation pattern. In the case of an array with deep pattern nulls, a relatively weak reradiated field can cause smoothing of the pattern, or null-filling. Because of the spectral crowding of the MF band such nulls are often specified to protect the coverage areas of other stations on the same frequency. Reradiation problems in these cases can result in violation of the station's licence requirements.

Methods for the analysis and prediction of reradiation problems can be of use to both broadcasters and regulatory agencies. Also, techniques for reducing scattering are needed for cases where unacceptable radiation pattern distortion occurs. While these situations have been dealt with individually in the industry, until recently detailed analysis has been rare due to the complexity of the problems. A notable exception is the work of Alford and French [1]. The availability of general purpose computer programs for electromagnetic analysis has allowed several researchers to consider MF broadcast reradiation in greater depth, sometimes in conjunction with scale model measurements. Most have concentrated on power line scattering [2,3,4] and methods for reducing it [5,6]. Scale model measurements of highrise building reradiation were presented by Balmain and Belrose [2]. Computational modelling of building scattering has been described by Royer [7].

In this paper we present results of a study of highrise building reradiation, combining computational analysis with both scale model and full-size measurements. The effects of electrically imperfect ground and building materials are considered and several types of stub "detuners" are evaluated.

Computer Modelling of a Highrise Building

Numerical modelling of buildings was carried out using two computer programs which employ the "method of moments" to solve a variety of frequency domain electromagnetic field problems. For this technique the current on an antenna or scatterer is represented by a series of N expansion functions. If an appropriate set of N testing functions is inserted in the integral equation describing the current, a set of N algebraic equations is generated. These are solved for the current coefficients. The program of Richmond [8] uses piecewise sinusoidal expansion and testing functions to find the currents on any structure assembled from short, straight, thin-wire segments. The NEC (Numerical Electromagnetic Code) program [9] employs expansion functions with sine, cosine and constant terms, and a point matching technique. The currents may be defined either on thin wire segments or flat patches. The choice of program for a computation was made according to the different capabilities of the programs to analyze some structures or to calculate certain quantities. The different computational techniques were not considered. The input for the programs includes a geometrical and electrical description of a conducting structure and any of a variety of source types. The output may include the current distribution, far and near-zone fields, input impedance, radiation efficiency, gain and scattering parameters.

Highrise buildings are usually built on a frame of steel or reinforced concrete. The structural or reinforcing steel, together with pipes and wiring, form a conducting grid on which induced RF currents can flow. A similar grid can be constructed to represent a building for a thin-wire moment method computer program. Substantial simplification of the wire network is necessary to ensure reasonable computational costs. The lengths and spacings of the wire segments in the numerical model have been found to have a small effect on the scattering behaviour. However, quite sparse grids, with wire segments up to about 0.2λ in length have been used with no unexpected qualitative effects. Royer [7] has reported similar results. The radii of the wire segments were also found to affect the scattering slightly. For accurate modelling the grid density and wire size must be carefully chosen. Convergence with decreasing grid spacing may not be an appropriate criterion since a real building is not made from flat conducting sheets. Since neither factor appears to be fundamental many properties of building reradiation may be studied without considering their effects in detail.

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<u>Building Scattering and Detuning using a Simple Computer Model</u>

Figure 1 shows the computed distortion of the horizontal plane radiation pattern of a 100m high monopole antenna at 840 kHz caused by the building model shown, spaced 500m from the antenna. Each wire segment in the model has a radius of 0.1m and a conductivity of 10^6 S/m. The segments describing the image of the antenna and building in perfectly conducting ground were included explicitly in the computation. The pattern is given as the vertically polarized gain of the total structure (including image) with respect to an isotropic source. Since the pattern maxima and minima are equal the scattering must be close to omnidirectional. The ratio S of the scattered field to the unperturbed field from the antenna may be found from the notch depth N, the ratio of the minimum total field to the unperturbed field, using the relation

$$S = 20 \log_{10} (1-10^{N/20}) \qquad (1)$$

where both S and N are in dB[2]. In this case the notch depth is -1.2dB so S is about -18dB. If we assume that the field incident on the building is inversely dependent on the distance from the antenna, the spacing would have to be 2 km for the scattered field to be 30dB less than the unperturbed field. Therefore, even at this distance there could be a noticeable effect on the pattern of an array with deep null requirements.

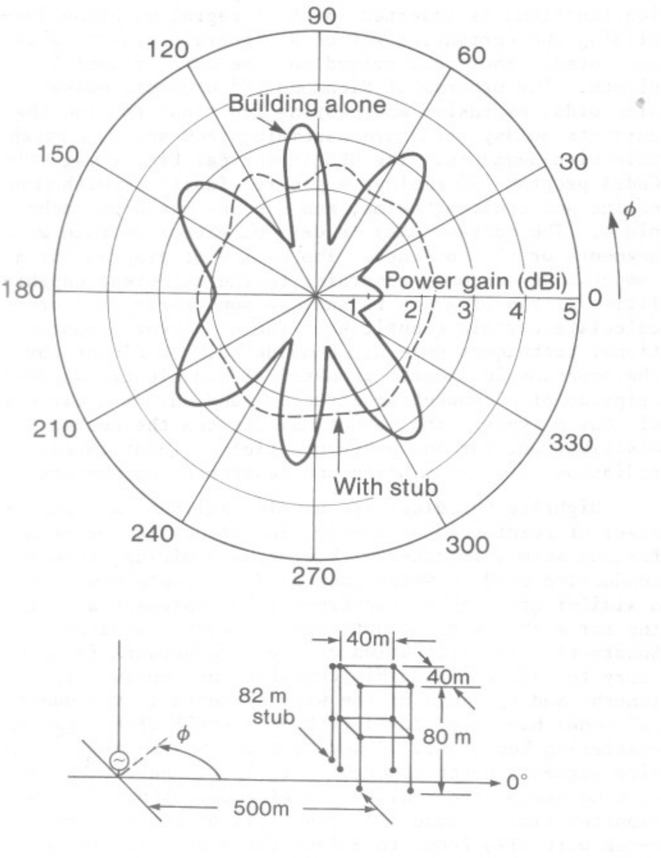

Fig.1 Computed 840 kHz radiation patterns of monopole near building with and without vertical stub.

In power line reradiation cases, vertical resonant stubs are sometimes attached to the power line towers to reduce scattering. This technique may also be applied to highrise buildings [7]. Figure 1 shows the effect of attaching a stub made of 82m of wire (0.230λ at 840 kHz) to a top corner of the building model. The wire radius (0.1m) and conductivity (10^6 S/m) are the same as those of the building wires. The pattern is much closer to being circular, and the scattered field is about 29dB below the unperturbed field, an improvement of 11dB. Some increase in scattering at high angles (from the horizontal) is observed when the stub is added, implying that the power formerly scattered horizontally may be redirected upwards. However, calculation of absorption and scattering cross-sections using Richmond's program shows that this is not the case. These cross-sections are defined by

$$\text{Absorption Cross-section} = \frac{\text{Total dissipated power}}{\text{Incident power density}}, \qquad (2)$$

$$\text{Scattering Cross-section} = \frac{\text{Total scattered power}}{\text{Incident power density}} \qquad (3)$$

They are plotted versus frequency in Fig.2, for the building model with and without the vertical stub, with plane wave excitation. In fact, the scattering cross-section (and thus the total power scattered) is reduced about 9dB by the stub at 840 kHz. The increase in absorption is insufficient to account for the decrease of scattered power.

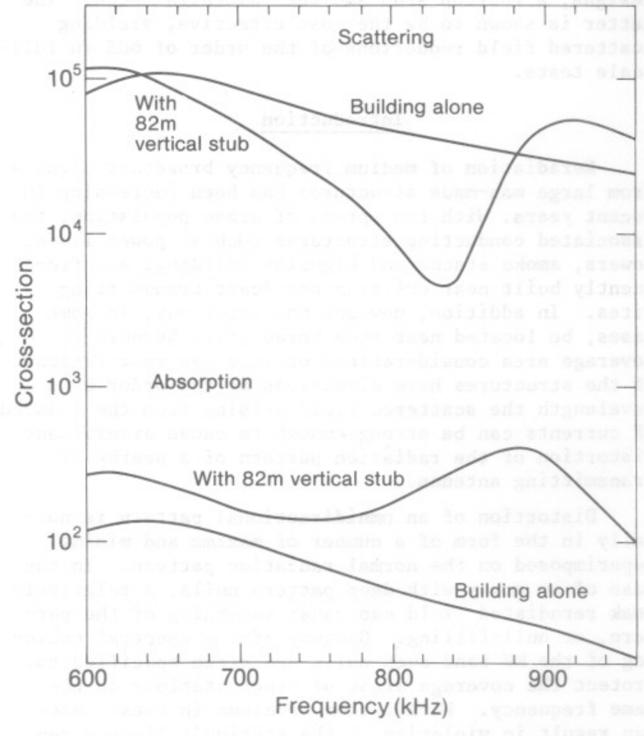

Fig.2 Computed frequency dependence of scattering and absorption cross-sections of simple building model with and without vertical stub.

Figure 3 shows the computed effect of a stub connected to the building at one corner of the roof but with the wire running around the edge of the roof 3m above it. The building and antenna are the same as in the previous example. This rooftop stub, containing 114m of wire, reduced the scattered field from 15dB to 34dB below the unperturbed field at 690 kHz. At this frequency the stub length corresponds to 0.262 wavelengths.

A modified version of the rooftop stub is shown in Fig.4. This "umbrella" stub makes use of substantial capacitive top-loading. With a plane wave incident on the building the scattering cross-sections were calculated with this umbrella stub and a 91m rooftop stub,

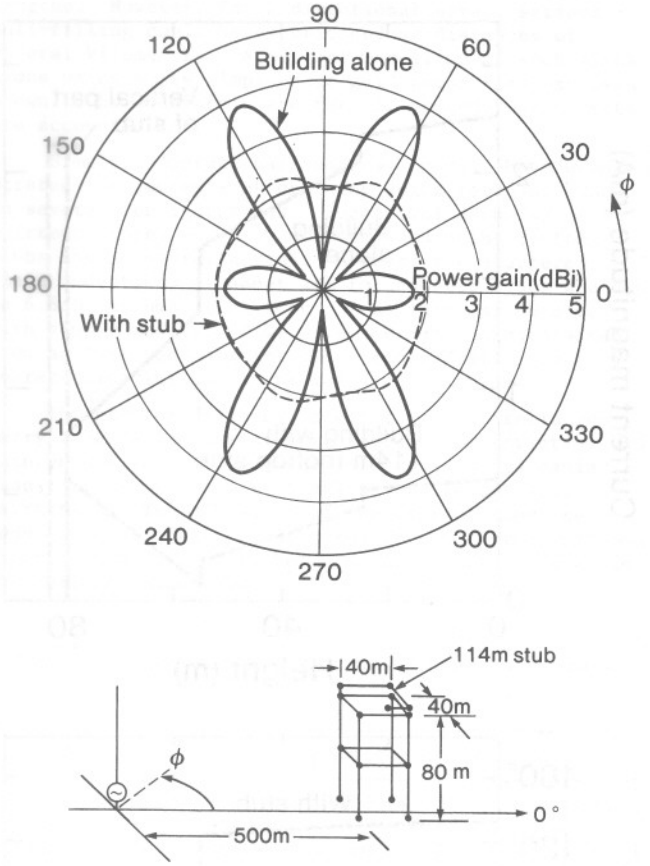

Fig.3 Computed 690 kHz radiation patterns of monopole near building with and without rooftop stub.

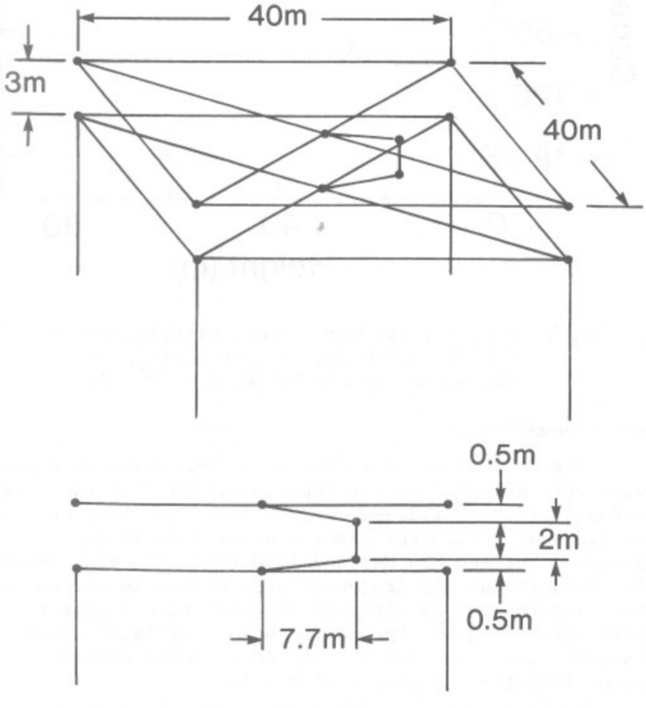

Fig.4 Umbrella stub computational model.

both having radii and conductivity equal to those of the building wires. These are plotted against frequency in Fig.5. Since both curves show the detuning effect to be maximum at about 840 kHz, comparison with Fig.2 is also possible. Again, a true reduction of reradiated power is observed in each case. The umbrella was the most effective, yielding a 17dB reduction of scattering cross-section, compared to 11dB for the rooftop stub and 9dB for the vertical stub.

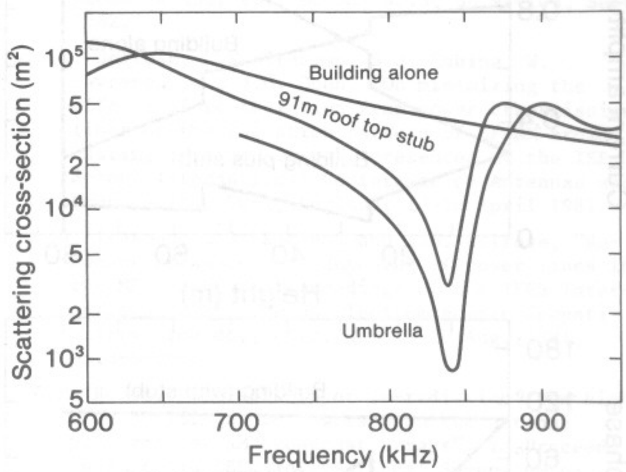

Fig.5 Computed frequency dependence of scattering cross-sections of simple building model with and without rooftop detuners.

Induced Current Distributions

In order to study the mechanism of stub detuning, the RF currents induced on the building and stubs were computed for each of the three stub types. In order to obtain more current samples over the height of the building, a model with smaller grid spacing was used. While the outer dimensions were the same as in the preceding examples, there were three vertical wires (including the corner wires) and two horizontal wires between the roof and ground on each side. A wire cross connected the centres of the edges of the roof. The currents at the ends of each vertical wire segment were calculated. The currents at each level were added vectorially to obtain a current value for the entire building (and detuning stub, when appropriate). These values were plotted against height for cases with and without detuning stubs present. Since few current samples were available the points were connected by straight lines.

Figure 6 shows the effect of an 82m long vertical stub at 855 kHz. A 100m monopole spaced 500m from the building was used as a source. The current on the building alone is approximately sinusoidal in distribution. With the stub present, the building current in a detuned condition is greatly reduced near ground level but much increased near the top. However, when the stub current is included in the summation, the total is low over the height of the building. This low total current results in reduced reradiation.

Clearly, for the case of a rooftop stub or umbrella a different mechanism accounts for the detuning effect, since the stub does not run vertically. The effect of a 114m rooftop coil at 680 kHz may be seen in Fig.7. The same monopole source was used. The current over the entire height of the building is substantially reduced in the detuned condition, although the stub current is very high. In addition a near-reversal of phase occurs near the top of the building. The overall reduction of induced current causes a decrease in scattering, and in addition the phase reversal causes scattered field cancellation near the horizontal plane.

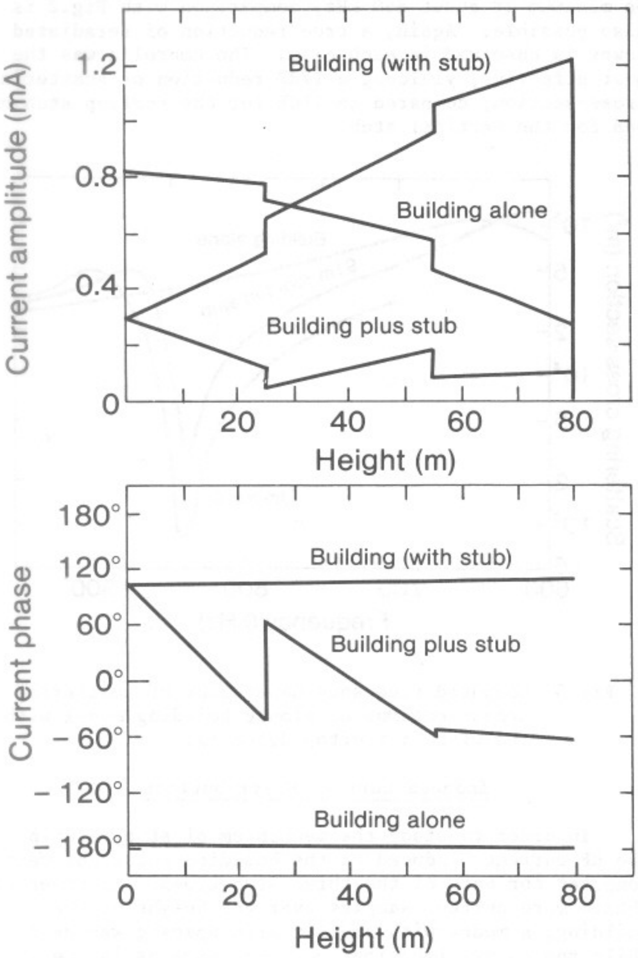

Fig.6 Computed 855 kHz current distribution on building with and without vertical stub (all wire radii = 0.1 m, $\sigma = 10^6$ S/m).

Figure 8 shows the currents on a building detuned by an umbrella stub at 755 kHz. In this case plane-wave excitation was used. The curves are similar to those for the rooftop stub but the phase change is more marked. It is apparent that these two stub types share the same mode of operation.

Scale Model Measurements

A program of UHF measurements was carried out to determine the scattering characteristics of a scale model building, both with and without detuning stubs. The aluminum building model was 160mm high and 38mm square (with 6mm radius rounded corners), corresponding to an 80m high building on a scale of one to one-thousand. Each end was closed with an aluminum "roof". The model building and a log-periodic receiving antenna were mounted on a rotatable support structure as shown in Fig.9. The receiving antenna centre was 51cm from the nearest face of the building. The horizontal-plane radiation patterns were measured, for the antenna alone, the antenna and building, and the antenna and detuned building. The perturbations from the normal antenna pattern were used to estimate the scattered field level, employing Equation (1). In addition, corrections were required for the receiving antenna pattern and to account for the fact that the transmitting antenna was not in the far field of the receiving antenna/building

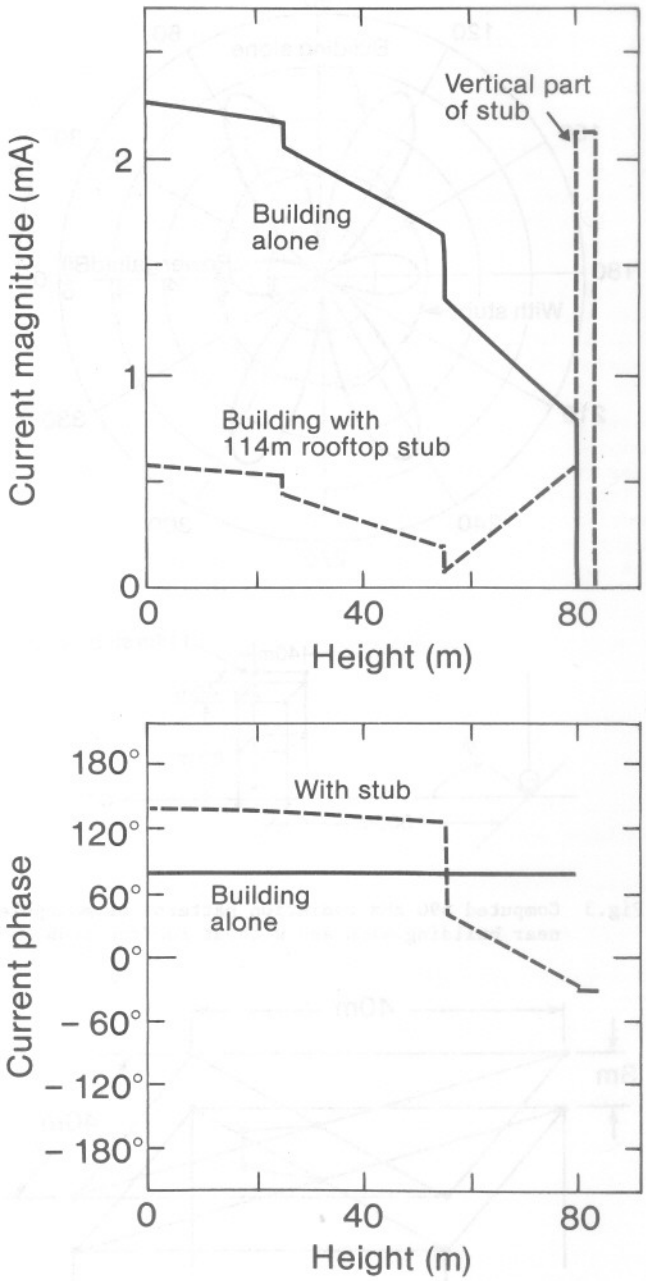

Fig.7 Computed 680 kHz current distribution on building with and without rooftop stub (all wire radii = 0.1 m, $\sigma = 10^6$ S/m).

model combination.

Vertical stubs of 1.02mm or 0.20mm diameter copper wire were attached to the top and bottom (for the image) corners of the building. For various stub lengths reductions of horizontal plane scattered field were observed between 800 MHz and 1000 MHz. The stub lengths for detuning at any frequency were within 10 percent of the computed values although the stub wire diameters were not to scale. The decrease in reradiated field obtainable was 7 to 14dB for the scale model compared to about 15dB for the numerical model.

Rooftop stubs of 1.02mm diameter copper wire also showed detuning effects very near the computed frequencies. Reductions of scattered field were typically 24dB at 650 MHz, 18dB at 800 MHz and dropping to 6dB at 1 GHz.

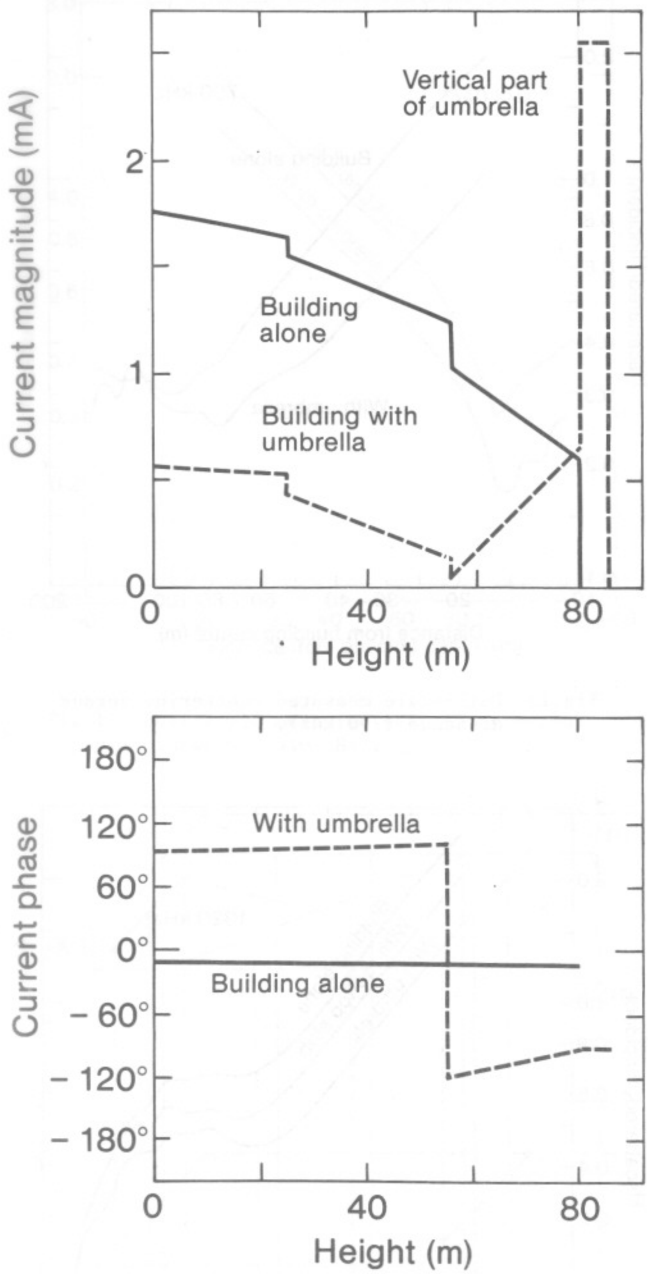

Fig.8 Computed 765 kHz current distribution on building with and without umbrella (all wire radii = 0.1 m, $\sigma = 10^6$ S/m).

For comparison, computed values were 21dB at 650 MHz and 14dB at 800 MHz.

Umbrella detuners were constructed of 1.02mm copper wire or brass rod of similar diameter. The detuning frequencies for these did not correspond as well with the computations because of the sensitivity to spacing from the roof. However reductions of horizontal plane scattering of 20 to 30 dB were measured, confirming the large detuning effect predicted by the computer program.

Full Scale Measurements

Full-size detuning stubs were tested on the thirteen storey reinforced concrete building shown in Fig.10. This building is 24.7m square and has an overall height of 45.4m to the penthouse roof. There is a lightning grounding system consisting of a network of wires at roof level and four downleads running inside the external columns and connected to ground rods. At roof level, the flashing over the safety wall, all equipment inside and outside the mechanical room and the lightning rods are connected to this lightning-ground system. Each external column contains ten continuously welded reinforcing rods. Although the terrain is flat several large nearby structures limited measurements to quite near fields. A similar building is located about 180m away, a slightly higher chimney is 300m away, and several hundred meters from the building is a major power line.

Only rooftop stubs and an umbrella were tried at this site because of the difficulty of safely constructing a vertical stub. Figure 11 shows the geometry of the rooftop stubs. The stub wire was 10 gauge copper (2.6mm diameter) and was supported at a height of about 2.4m from the roof by insulators hung from wooden masts. The stub was connected to the lightning ground system at one corner of the roof through a variable reactance. Figure 12 shows the umbrella geometry. Additional wooden supports on the penthouse roof were used. The

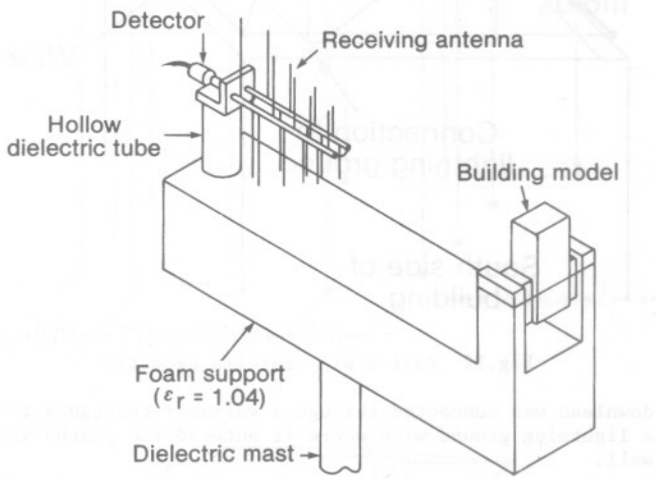

Fig.9 Rotatable mount for UHF measurement

Fig.10 Highrise building used in full-scale tests

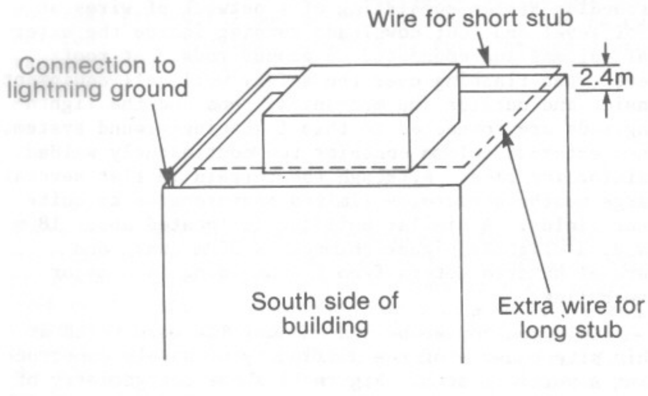

Fig.11 Full-scale rooftop stub geometry

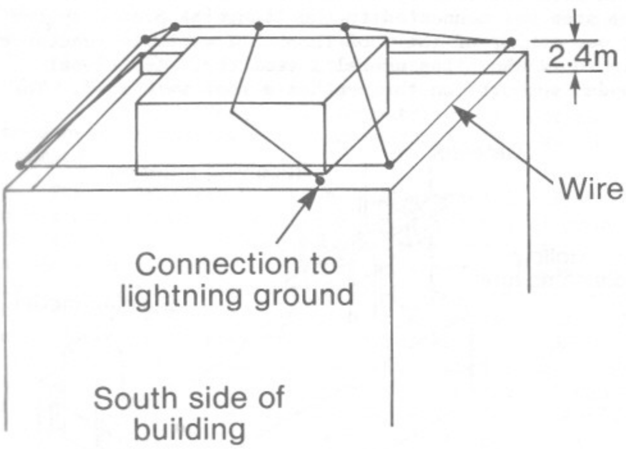

Fig.12 Full-scale umbrella geometry

download was connected through a variable reactance to a lightning ground wire where it entered the penthouse wall.

Existing MF broadcasting stations, up to 25 km away, were used as sources. Field strength measurements were made along lines extending radially from the building and perpendicular to the direction of incidence from the stations. The field strength meter was equipped with a loop antenna so it responded to magnetic field components. Along the radial lines it was possible to align the null of the loop pattern in the direction of either the incident or scattered field while the other field component was received in the loop pattern maximum. Such measurements of incident and scattered fields were made at regular intervals along the radial lines for the building alone and under detuned conditions. The detuned state was found by adjusting the tuning reactance on the roof to minimize the measured scattering at a point on the appropriate radial line near the base of the building.

Figures 13, 14 and 15 show the measured scattered fields plotted against distance from the building at 790, 1320 and 1540 kHz. The scattered fields are normalized to the measured incident field strength at each frequency. The reduction in scattered field near the base of the building can be clearly seen in each case. Figure 14 demonstrates that, as in the computations and model measurements, the umbrella was more effective than the rooftop stub. However the full scale near-field scattering reductions were generally much smaller, with no improvement better than 6dB. Because of the limitations imposed by scattering from other objects (apparent in the scattering curves at distances more than about

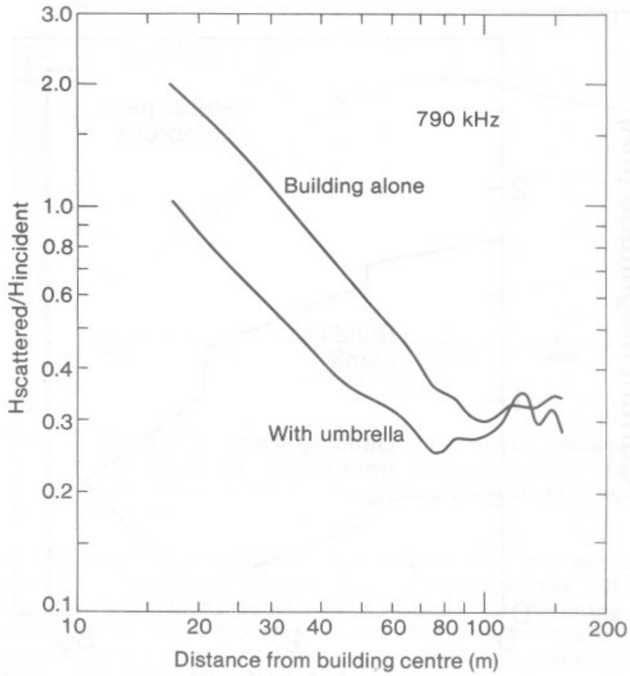

Fig.13 Full-scale measured scattering versus distance (790 kHz).

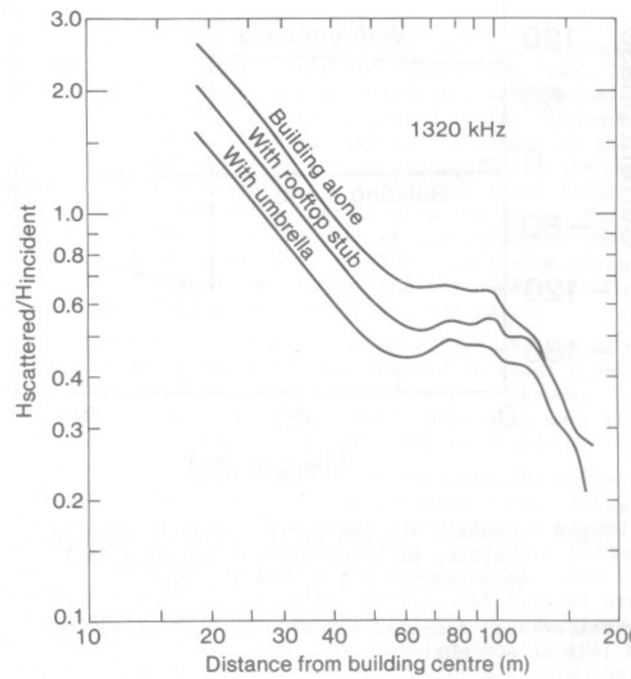

Fig.14 Full-scale measured scattering versus distance (1320 kHz).

60m) it was necessary to develop a more refined computational model to estimate the far-field scattering.

Improved Computational Model

The wire grid geometries chosen to represent the full-scale building are shown in Fig.16 (used for the building alone and with rooftop stubs) and Fig.17 (used with umbrella detuners). Since the actual building has

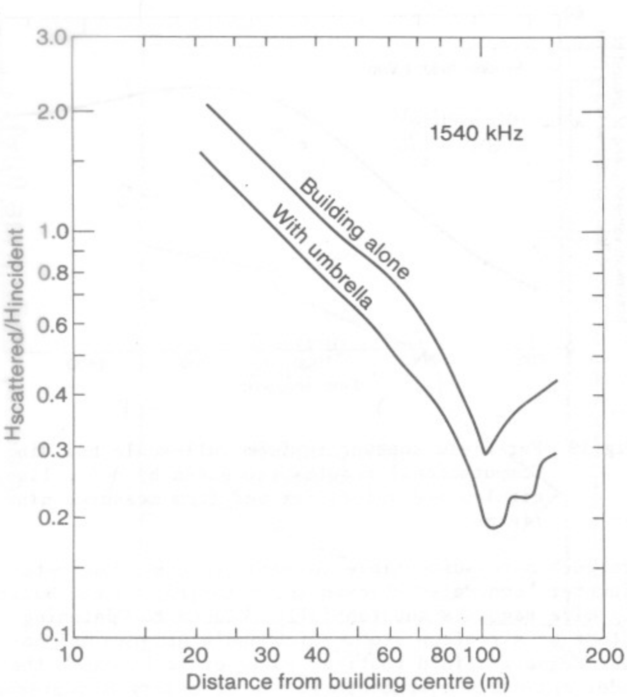

Fig.15 Full-scale measured scattering versus distance (1540 kHz).

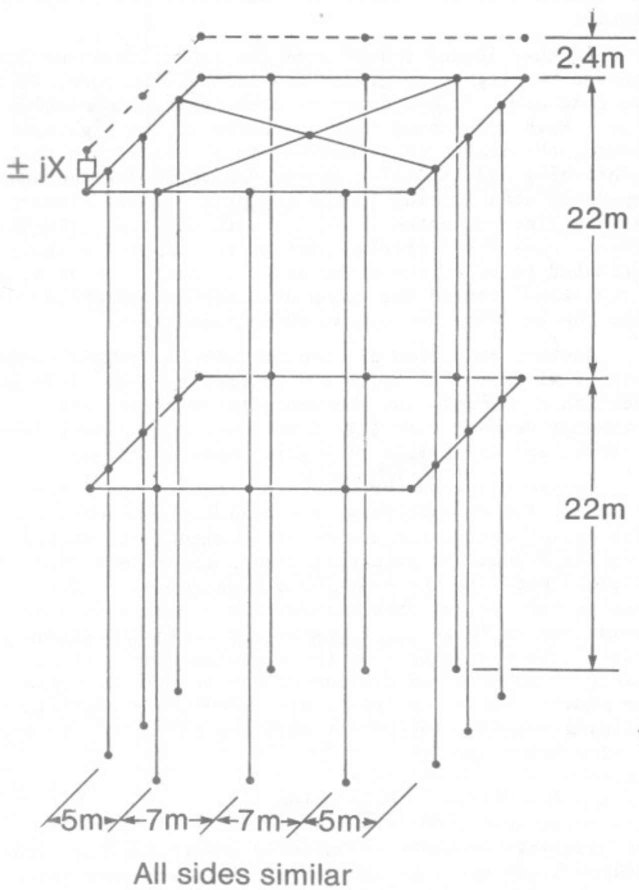

Fig.16 Improved computational model of building alone or with rooftop stub. Building wire radii = 0.1 m, variable conductivity; detuner wire radius to scale, σ = 5.8 x 10^7 S/m.

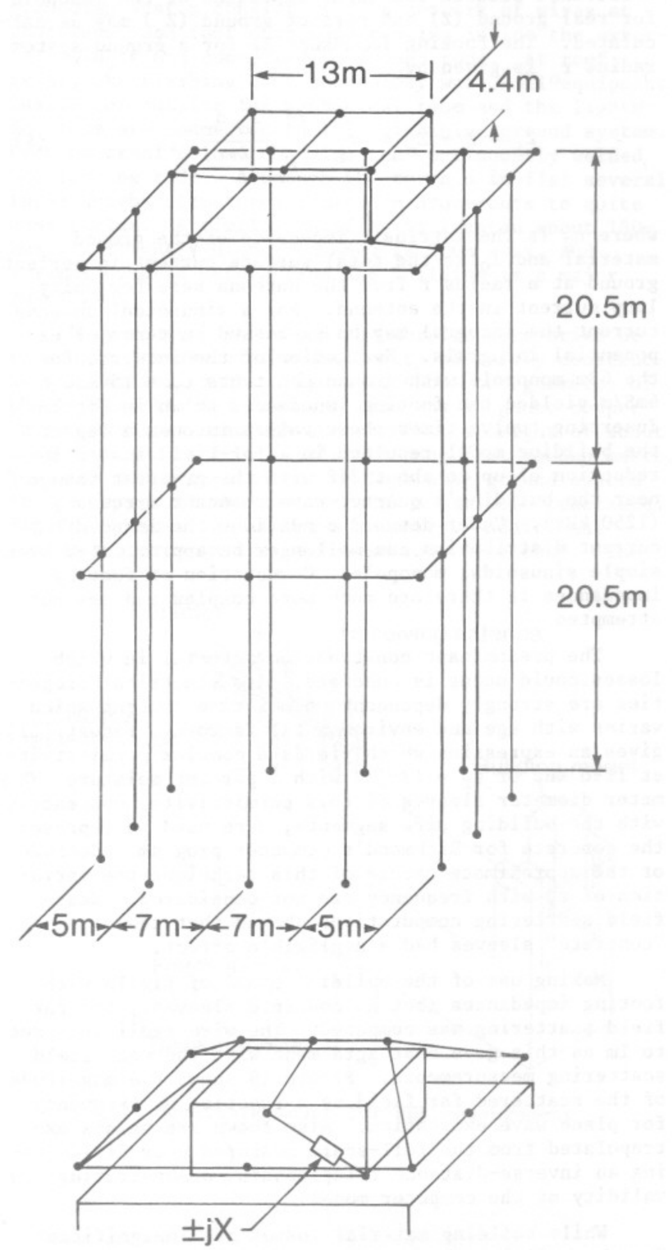

Fig.17 Improved computational model of building with umbrella. Building wire radii = 0.1 m, variable conductivity; detuner wire radius to scale, σ = 5.8 x 10^7 S/m.

no external columns at the corners, no corner wires were used. The more complicated representation of the roof region used with the umbrella model was necessary because of the sensitivity of the umbrella detuner to its capacitance to the roof beneath it.

In order to account for losses in finitely conducting ground, a lumped "footing impedance" was inserted between the base of the building model and a perfect ground. An approximate value for this impedance was obtained by making use of the compensation theorem technique described by Monteath [10]. To reduce the complexity of the calculations, the building was simplified to an infinitesimally thin 63m monopole over a 13.54m radius perfectly conducting ground system. The height was chosen to give the same resonant frequency as the building and the ground system area was equal to the building cross-sectional area. For this geometry the difference between the input impedance of the monopole for real ground (Z) and perfect ground (Z_o) may be calculated. The footing impedance Z_f for a ground system radius r_o is given by

$$Z_f = Z - Z_o \cong \eta_g \int_{r_o}^{\infty} \frac{I_o^2 \, d_r}{2\pi r} , \qquad (4)$$

where η_g is the intrinsic impedance of the ground material and I_o is the total surface current in perfect ground at a radius r from the antenna base for unity loop current in the antenna. For a sinusoidal antenna current the integral may be expressed in terms of exponential integrals. Evaluation of the integral for the 63m monopole with ground constants $\varepsilon_r = 15$ and σ = 6mS/m yielded the footing impedances shown in Fig.18. Inserting twelve times these values into each leg of the building model resulted in a far-field scattering reduction of up to about 2dB with the greatest change near the building's quarter-wave resonant frequency (1250 kHz). Under detuned conditions the induced current distribution can no longer be approximated by a simple sinusoidal monopole. Computation of footing impedances is therefore much more complex and was not attempted.

The predominant construction material in which losses could occur is concrete. Its electrical properties are strongly dependent on moisture content which varies with age and environmental factors. Paquet [11] gives an expression which yields a complex permittivity at 1190 kHz of ε_r = 13-j18 with 5 percent moisture. One meter diameter sleeves of this permittivity, concentric with the building wire segments, were used to represent the concrete for Richmond's computer program. Because of the approximate nature of this technique the variation of ε_r with frequency was not considered. Near-field scattering computations showed that these "concrete" sleeves had a negligible effect.

Making use of the building model of Fig.16 with footing impedances (but no concrete sleeves), the far field scattering was computed. The wire radii were set to 1m as this gave best agreement with the near-field scattering measurements. Figure 19 shows the magnitude of the scattered far field as a function of frequency for plane wave excitation. Also shown are values extrapolated from the full-scale measured near fields using an inverse-distance relationship, demonstrating the validity of the computer model.

While building material losses are insignificant for the building alone, sharply resonant detuning stubs are much more susceptible to such effects. One meter diameter "concrete" sleeves (ε_r = 13-j18) on the building wire segments substantially reduced the detuning effect of a rooftop stub. Richmond's program had no near magnetic field routine, so in order to check the model against measurements it was necessary to represent the effect of the concrete with the NEC program, which has no lossy sleeve capability. To do this the conductivity of the building wire segments of a NEC model was reduced to produce the same near E-field scattering as the concrete sleeve model. A conductivity of 20 S/m was required.

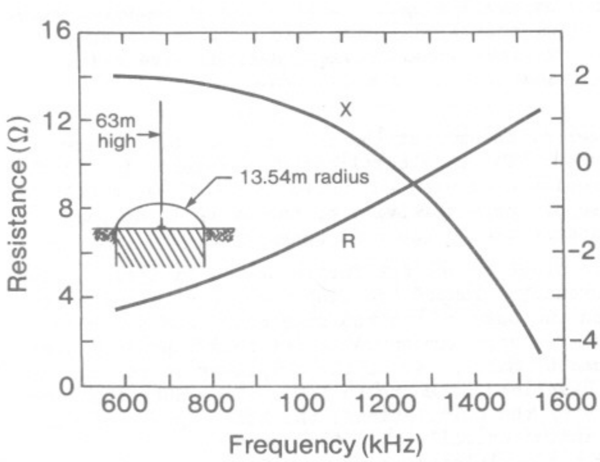

Fig.18 Computed frequency dependence of footing impedance.

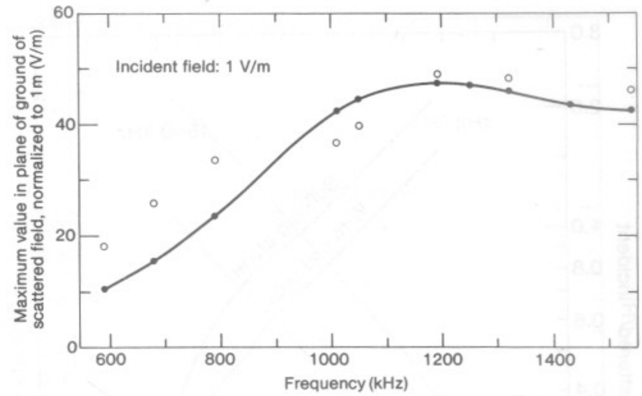

Fig.19 Far-field scattering from full-scale building. Computational results are given by solid line; circles are values derived from measured near fields.

Further losses result from the lack of a connection between the lightning ground and reinforcing rods. These two conductors form a concrete dielectric transmission line. With a detuning stub connected to the lightning ground, the scattering behaviour is the same with the reinforcing and lightning ground connected and the input impedance seen looking in the top of the lossy transmission line connected in series with the stub. For the present case the resistive part of the impedance was estimated to be of the order of 13Ω. Inclusion of such a resistance raised the detuned scattered magnetic field near the building by several dB in some cases.

Another reduction of detuning effect results if the detuner wires in the model are lowered to about 0.7m in order to compensate for the capacitance difference between a detuner over a flat roof containing many conductors, and the simple wire grid representation.

To use the computer model to estimate the full-scale far field scattering, the building conductivity, stub series resistance and detuner height were varied slightly around the predicted values to produce the best possible match to the near field measurements. The results for several frequency/detuner combinations are summarized in Table 1. Computed far-field reductions were slightly greater than the measured near field changes. Maximum and minimum values for all azimuths are shown. These results clearly show the potential of building material losses for reducing the effectiveness of stub detuning.

Conclusions

Analysis of highrise building scattering has demonstrated behaviour like that of a thick, somewhat lossy monopole with a broad resonance near a height of 0.18 wavelengths (for horizontal dimensions of about half the height). Reradiation from a building near resonance could be strong enough to cause significant radiation pattern distortion in the case of an omnidirectional antenna for spacings up to about two or three wavelengths. However, for a directional array, serious null-filling could be experienced at distances of several kilometers. Numerical modelling of such situations using quite simple wire grid geometries has been shown to be moderately accurate if ground loss effects are accounted for.

Simple computational and scale models have demonstrated the concepts of detuning using resonant stubs in several configurations. Successful detuning of a thirteen storey building was achieved using rooftop stubs and an umbrella stub. However the scattered field reductions of about 2dB for rooftop stubs and 4.4 to 6.6dB for umbrellas were not as large as observed with simple models. Similar performance was obtained from an improved computer model incorporating factors representing losses in the building materials.

The greater detuning effect of the umbrella geometry appears to make it more useful. Construction and maintenance for this and the rooftop stub are easier than for the vertical stub making the latter less attractive. The behaviour of the improved computer model suggests that the detuning levels already achieved might be improved by techniques for reducing losses in the building materials.

Table 1. Improved computer model detuning summary

	Rooftop stubs		Umbrella	
	1320	1540	790	1320
Building conductivity(S/m)	20	20	10	10
Series resistance (Ω)	20	20	10	20
Height over penthouse (m)	-	-	0.7	0.7
Height over roof (m)	0.7	0.7	2.4	2.4
Computed far-field (dB) reduction	2.1-2.6	1.4-1.7	5.7-6.6	4.4-5.2
Measured near-field (dB) reduction	1.9	0.9	5.4	4.3

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