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REDUCTION OF MUTUAL COUPLING IN A MULTI-BAND MICROSTRIP WINDOW ELEMENT

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ABSTRACT: Mutual coupling between two circular window elements has been reported in various papers and the results indicate that mutual coupling level is greater for the window patch antennas than for the normal patches due to cylindrical waves which are trapped by the metal of the low frequency element and these cylindrical waves are added to the radiative waves to increase the mutual coupling level. Since mutual coupling between antenna elements in an array can be problematical, some techniques will be presented in this paper to reduce the mutual coupling between elements in a multi-band window element depending on the phase cancellation between the radiative and the trapped waves.

1-INTRODUCTION: Microstrip antenna technology [1] is continuous to be a growth area in modern system design. One advantage of the technology is the opportunity to combine two or more antennas in one device. In addition, microstrip patch antennas have desirable features such as low cost and light weight which make them extremely attractive candidates for use in a variety of applications.

Recently, a novel multi-band microstrip antenna element offering a band separation of 6: 3: 1 has been presented [2]. The design is based on the window concept whereby higher frequency elements can be housed within low frequency elements provided that they are isolated by a window gap in the low frequency conductor. This allows substrate trapped waves to propagate in addition to the radiative waves causing an increase in mutual coupling levels. The results [3] indicate that mutual coupling levels between window elements are higher than for normal elements and increase as the window size reduces.

Since high coupling levels between elements in an array can be problematical, some techniques will be presented here to reduce the mutual coupling between elements in the multi-band window element. The main idea is to control the amplitude and phase of the trapped waves so that it can be cancelled by the radiative waves for certain substrate type and at certain separation distance between patch elements.

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2-PARAMETERS AFFECTED ON WINDOW COUPLING: Mutual coupling between window antennas shown in Fig.1 is assumed to be the sum of the radiative and trapped waves coupling. The parameters that affected on radiative wave coupling have been reported in many papers [4, 5]. In general, radiative coupling increases for higher dielectric permittivity ε_r, lower separation distance w/λ, and higher substrate thickness h/λ. In this section, we will concentrate on parameters which affect on the trapped waves coupling.

Trapped coupling is due to waves which are guided by multiple reflections between the ground plane and the low frequency patch conductor. This coupling is given by [3]:

$$|S_{12}| = 20 \log_{10} \left| \frac{-Y_{12}}{2Y_0} \right| \qquad (1)$$

where: S_{12} is the trapped waves coupling
Y_0 is the self patch admittance
Y_{12} is the mutual admittance between the two window antennas due to the trapped waves and is given by:

$$Y_{12} = \frac{-r_2}{M_1 M_2 (2h)} \int_{-\pi}^{+\pi} \bar{H}_2 \cdot \bar{M}_2 \, d\phi \qquad (2)$$

where: M_1 and M_2 are the magnetic currents on the window patches (1) and (2)
r_2: is the window patch radius
h: is the substrate height
H_2: is the magnetic field on patch (2) due to the current source M_1 of the patch (1)

Fig.2 shows the theoretical mutual admittance Y_{12} between two window elements as a function of separation distance w/λ, based on eqn.(2), for different substrate types (foam or plastic). The window antenna operates at 6 GHz and with Δr = 4 mm. The results indicate that substrate with higher permittivity has higher mutual admittance and as the separation distance between window elements increases mutual admittance decreases.

Fig.3 shows the calculated mutual conductance and susceptance (G_{12} and B_{12}) of radiative and trapped waves as a function of separation distance w/λ between the two window elements, given in Fig.1, printed on phasic substrate with ε_r = 2.32, Δr = 4 mm, and operating at 6 GHz. The results obtained are based on eqn (2) and show that G_{12} and B_{12} behave as damped oscillation w.r.t. separation distances and their values are out of phase for $\lambda<w<2\lambda$ which is the key point in wave coupling cancelation.

3-COUPLING REDUCTION BETWEEN WINDOW ELEMENTS IN THE MULTI-BAND ANTENNA ELEMENTS: Mutual coupling effects between two window elements have been investigated [3] where the theoretical and experimental results show that the coupling level between window elements is a little higher than for isolated patches and, on very low permittivity substrates, the mutual coupling between window elements can be reduced significantly for certain element spacings. This reduction is strongly depending on phase variation of the trapped waves underneath the patch surface. The dashed-line in Fig.4 shows the measured E-plane mutual coupling between two window elements built on foam substrate with window size Δr = 2 mm, patch radius r_2 = 11 mm, ε_r = 1.05, and with different separation distance w.

The E-plane mutual coupling between two isolated patches on foam substrate has also been measured, solid-line in Fig.4, with the same parameter to show the function of the trapped waves with the separation distances on the reduction of mutual coupling between window elements. From Fig.4, the coupling level for the isolated patches is less than for the window elements, but for the distance $0.56\lambda \leq w \leq 1.1\lambda$, the coupling level for the window elements is lower than the isolated patches. A null (coupling level ≅ - 45 dB) can be obtained between window elements for a wave length (λ) separation distance and relative permittivity ε_r = 1.05 which is very good in array design.

In addition to the reduction of coupling in the window concept through a very low permittivity substrate, one can reduce the coupling level by using sequential rotation [6] of the notches in the window elements. Fig.5 shows the reduction in the measured coupling level at 3.6 GHz, due to the use of the sequential rotation technique, between two window patches printed on plastic substrate with relative permittivity ε_r = 2.32 and thickness h = 0.02 λ. Generally the reduction in coupling is in the range of 5 dB for w = 0.58 λ and up to 11 dB for w = 1.17 λ.

4-COUPLING REDUCTION BETWEEN SLOT ELEMENTS IN THE MULTI-BAND ANTENNA ELEMENTS: Coupling between ordinary slot elements has been reported [7] with a high coupling level due to the presence of higher order modes. One way to reduce coupling between slot elements is with shorting pins [7]. This technique can't be used to reduce coupling between slots in the triple-band element [2] since these shorting pins will damage the low frequency element. But alternatively, one can use a very low permittivity substrate. As for the window elements, it has been found here that the separation distance between two slots can be chosen to achieve a minimum coupling level. The coupling between two annular slots shown in Fig. 6(a) has been measured to show the effect of the trapped waves on the coupling mechanism. For comparison coupling between two annular rings, given in Fig.6(b), has been measured where the trapped wave effect is absent.

The measured mutual coupling, Fig.7(a), between two annular slots of width Δ_s = 2 mm, printed on foam substrate with permittivity ε_r = 1.05 and h = 1.58 mm, shows a deep null (mutual coupling = - 46.5 dB) at a separation distance w = 0.5 λ which illustrates the effect of the trapped waves underneath the metallic conductor. The null phenomenon in mutual coupling between slot elements dose not exist between annular rings as shown in Fig.7(b).

Fig.7(b) shows the measured coupling between the two annular rings printed on foam substrate (ε_r = 1.05, h = 1.58 mm), as a function of separation distance (w/λ), for different annular ring sizes (Δ_r = b - a) 2, 4, and 6 mm. The measured results show that the wider ring has the higher coupling within the range of maximum 5 dB for separation distance w = 0.5 λ otherwise the coupling difference is in the range of 3 dB. Generally, the mutual coupling decreases as the separation distance increases for the three different ring sizes. Finally, from Fig.7(a) and (b), one can notice that the coupling between slots is higher than that between rings for small separation distance ($w/\lambda \approx$ 0.4), but for $w/\lambda > 0.6$, both have approximately the same coupling level.

5-CONCLUSION: Theoretical results showed the effect of substrate type on the trapped waves with mutual admittance as a function of separation distances. A null can be achieved between window elements for a wave length (λ) separation distance and with very low relative permittivity (ε_r). In addition, coupling level can be reduced by using sequential rotation of the notches in the window elements. For mutual coupling between slot elements (in the multi-band antenna element), it can also be reduced using very low permittivity but at separation distance equal to a half wave length. This reduction is due to a strong effect of the trapped waves, which is not observed in the measurement of isolated patches or ring antennas.

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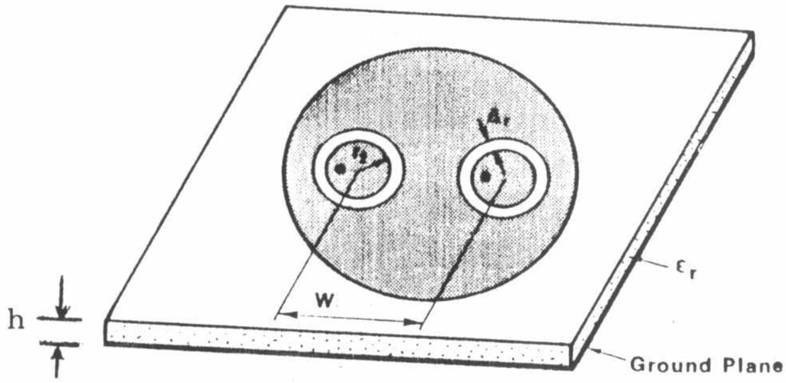

Figure 1: Configuration of two window elements

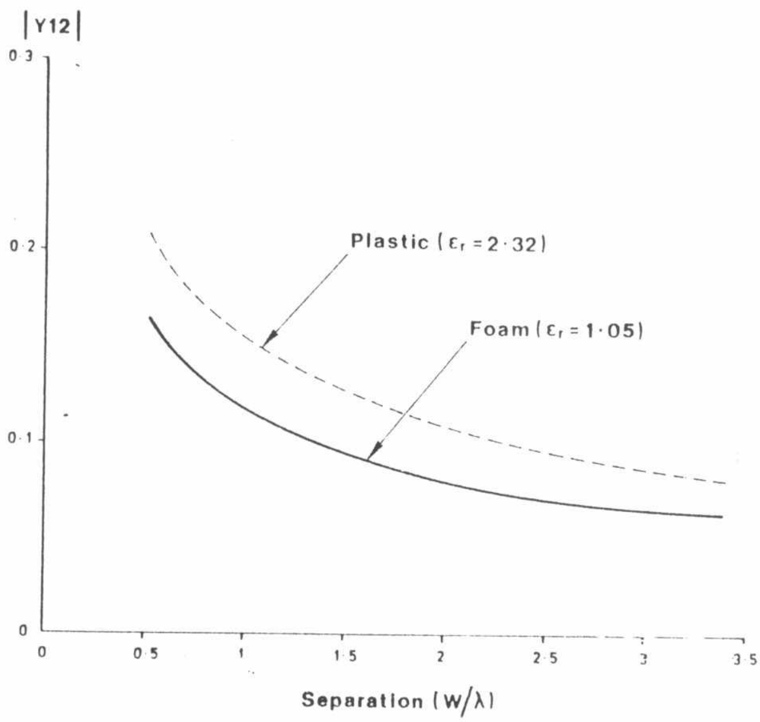

Figure 2: Effect of substrate type on trapped waves mutual admittance versus separation distance (w/λ)

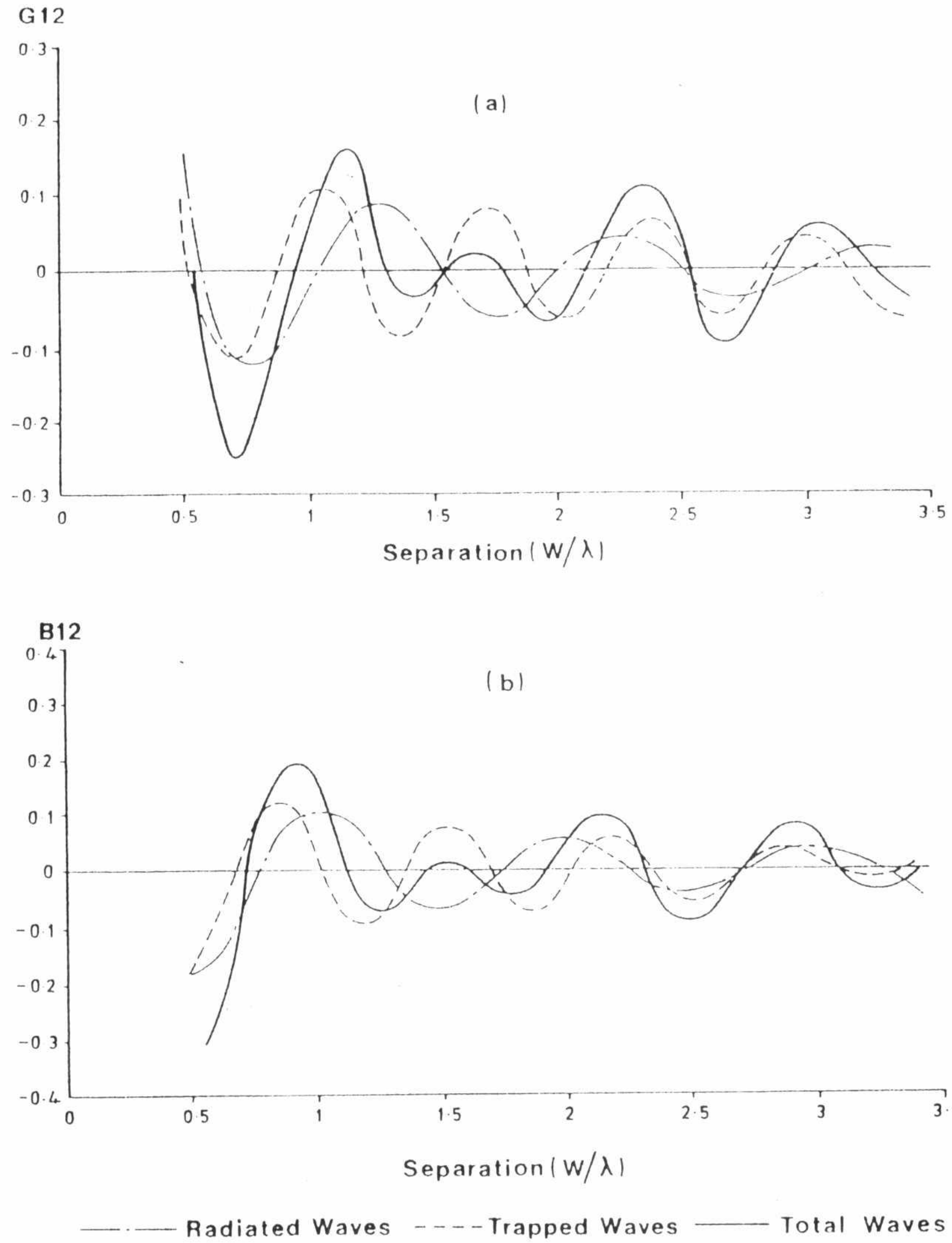

Figure 3: Calculated mutual admittance of a window antenna element on plastic substrate:
(a) Mutual conductance G_{12}
(b) Mutual susceptance B_{12}

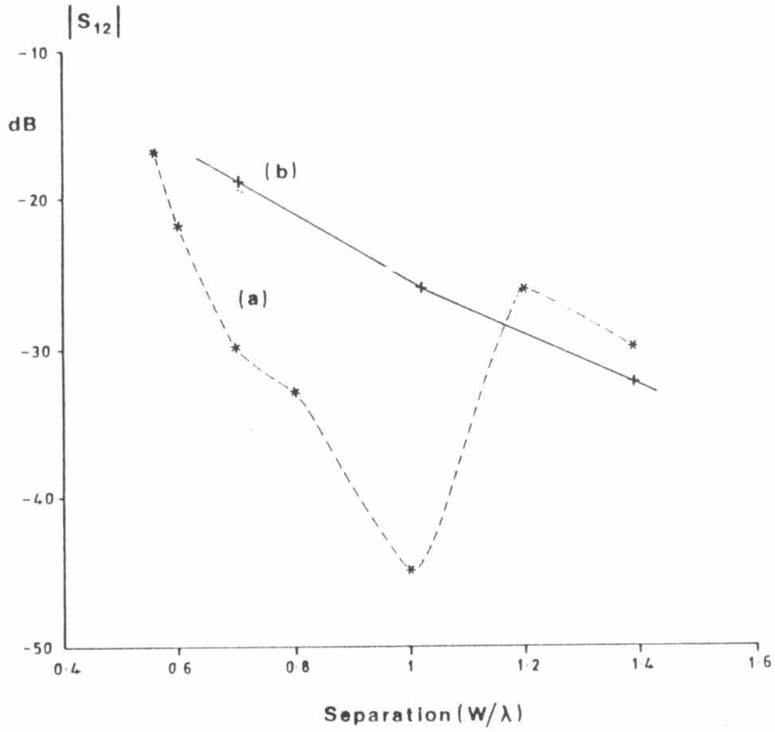

Figure 4: E-plane mutual coupling measurements of the antenna shown in Fig. 1 with $\epsilon_r = 1.05$, $r_2 = 11$ mm for:
(a) Window elements $\Delta r = 2$ mm
(b) Isolated patches $\Delta r = \infty$

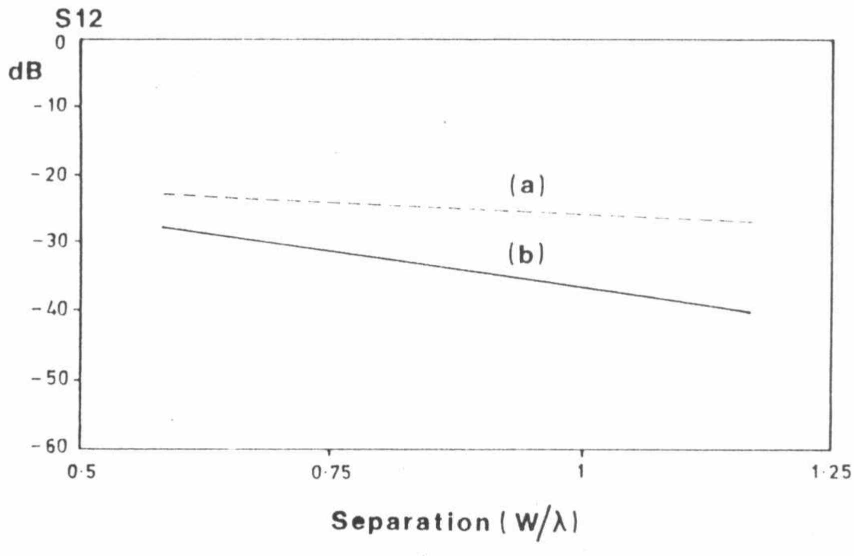

Figure 5: Measured coupling between two window elements
(a) E-E Normal coupling
(b) E-H Sequential coupling

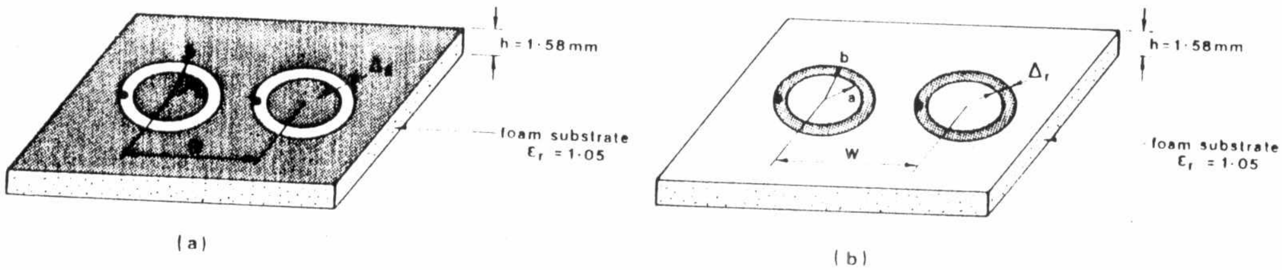

Figure 6: Elements configuration for:
(a) Two annular slots of size $\Delta_s = b - a$ (mm)
(b) Two annular rings of size $\Delta_r = b - a$ (mm)

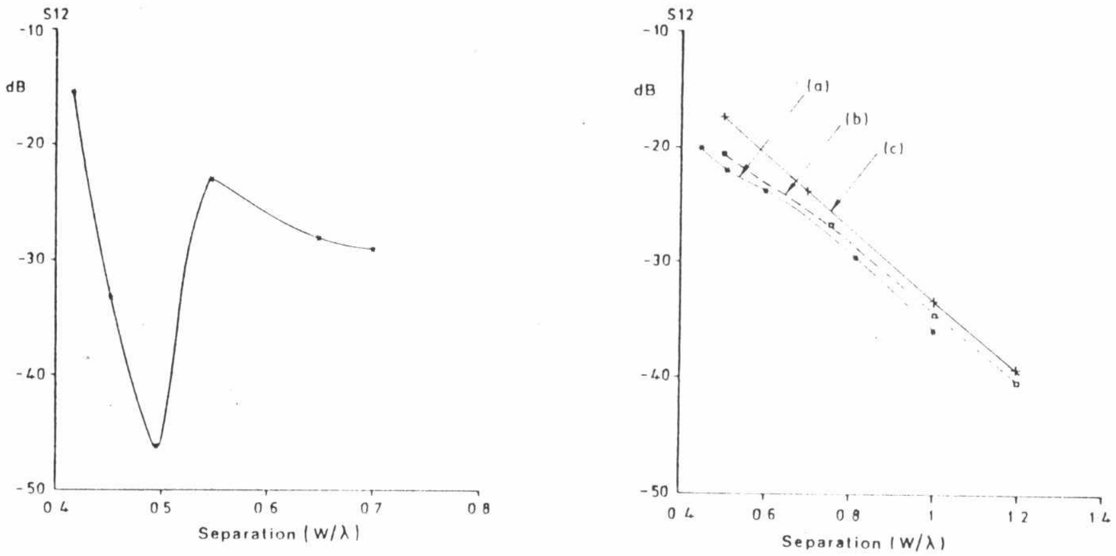

Figure 7: Measured coupling S_{12} between:
(a) Two annular slots shown in Fig. 6(a) for: Δ_s = 2 mm
(b) Two annular rings shown in Fig. 6(b) for:
(I) Δ_r = 2 mm (II) Δ_r = 4 mm (III) Δ_r = 6 mm