ACTIVE MICROWAVE SURFACES

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Abstract

The requirements for realising microwave surfaces having a controllable reflection coefficient are reviewed and examples of possible applications are presented.

Background theory and applications

Consider the general case of an electromagnetic wave incident on a semi-infinite medium whose constituent electrical parameters can in some way be switched repetitively between two states A and B, thus resulting in front face reflection coefficients ρ_A and ρ_B. For the medium to behave as a perfect absorber, as seen on a time-averaged basis, then ρ_A and ρ_B are related by [1]

$$\Gamma_{av} = \frac{1}{T}\int_0^T \rho(t)\,dt = \frac{1}{T}\left[\tau\rho_A + (T-\tau)\rho_B\right] = 0 \tag{1}$$

where τ is the time during which the medium is in state A and T is the period of the stimulus controlling the electrical state of the medium. If the normalised medium admittances corresponding to ρ_A and ρ_B are Y_A and Y_B, respectively, then from (1) the following general relationship holds

$$Y_A Y_B + (1-\frac{2\tau}{T})(Y_B - Y_A) = 1 \tag{2}$$

For a homogeneous medium, (2) defines the relationship between the medium parameters μ and ε in the two states A and B

$$\sqrt{\frac{\varepsilon_A\varepsilon_B}{\mu_A\mu_B}} + \left(1-\frac{2\tau}{T}\right)\left(\sqrt{\frac{\varepsilon_B}{\mu_B}} - \sqrt{\frac{\varepsilon_A}{\mu_A}}\right) = 1 \tag{3}$$

In the simplest case, when $\tau/T = 0.5$, then (3) gives

$$\sqrt{\frac{\varepsilon_A\varepsilon_B}{\mu_A\mu_B}} = 1 \tag{4}$$

(4) implies that in its two states, the medium must have admittance values which lie above and below that of free-space, Y_0.

In practice, a switchable medium must have a finite thickness; hence a zero time-averaged reflection coefficient can only be realised over a finite band of frequencies. A practical switchable medium might take several forms. To date, we have explored (a) a dielectric layer terminated by a PEC and (b) structures similar to the classical Salisbury screen and Jaumann absorbers in which the resistive sheets have been replaced by thin active FSS containing diode-loaded resonant elements. In case (b) the termination might be a PEC, a PMC or a particular admittance chosen to increase the structure functionality (e.g. a semi-transparent back-plane). When the termination is a PEC, (2) becomes

$$[Y_A - j\cot(\beta d)][Y_B - j\cot(\beta d)] + \left(1-\frac{2\tau}{T}\right)\left(Y_B - Y_A\right) = 1 \tag{5}$$

where d is the layer thickness and Y_A and Y_B are the normalised admittance states of the FSS. When d = $\lambda/4$, (5) simplifies to

$$Y_A Y_B + \left(1 - \frac{2\tau}{T}\right)\left(Y_B - Y_A\right) = 1 \quad (6)$$

This implies that even if the values of Y_A and Y_B are not optimum, then adjustment of τ can ameliorate matters. This is of use in practical structures since the total surface area of the conducting patterns comprising the active FSS is always smaller than the area of the PEC back-plane (i.e. ρ_A and ρ_B in (1) have an implicit surface area dependence [2]). When $\tau/T = 0.5$, then (6) simplifies to

$$Y_A Y_B = 1 \quad (7)$$

Hence, provided that the two admittance states of the active FSS can be switched to values greater than and less than that of free-space, then the active structure can always be made to exhibit some reduction in its apparent time-averaged reflection coefficient.

Although the above discussion throws light on the required relationship between Y_A and Y_B, it does not explain how the structure works since it can only reflect the incident wave rather than absorb it; for this, we need a spectral approach. Although in both states, the structure presents a reflection coefficient magnitude of 1 to the incident wave, the phase angles differ (ideally by 180°). Hence the reflected wave is binary phase modulated and has a spectrum in which the component at the incident frequency is suppressed, with its energy being redistributed into sidebands which will lie outside the receiver bandwidth if the switching frequency is high enough. Thus, to the receiver, the structure appears to be reflecting less energy than when it is not switched and so it appears to act as an absorber. This then is the mode of operation of the Phase-Switched Screen (PSS). The degree of "absorption" offered by the PSS is proportional to the switching frequency since this determines the separation of the reflected signal sidebands; hence a high switching frequency is desirable. A simple method of increasing this is to replace each diode in the FSS by an anti-parallel diode pair which then acts as a frequency doubler [3].

Although the incident frequency component is suppressed on reflection from the PSS, it might still be possible to detect a PSS-covered object by looking for any high amplitude sideband components in the reflected signal spectrum. This can be countered by choosing appropriate switching waveforms [4]. As an example, Figure 1 shows the predicted effect on a simple pulsed radar signal of applying a 256 bit switching code to a single layer PSS. For comparison, the figure also shows the spectrum of the incident radar signal and that reflected from the PSS when regular square wave switching is used [5]. It can be seen that the 256 bit code leads to a worthwhile reduction in the reflected signal at all sideband frequencies (about 20dB). This type of switching code is also effective against pulse compression radars since it degrades the correlation process in the receiver [6].

As mentioned earlier in the discussion, ρ_A and ρ_B in (1) have an implicit surface area dependence. This fact can be used to provide a degree of control over the radar cross-section (RCS) of an object even when it is not covered totally by a PSS. As an example, Figure 2 shows some measured reflectivity data for a 47mm diameter cavity-backed spiral antenna when surrounded by a PSS boundary one FSS cell wide. It can be seen that at selected frequencies, dynamic changes in RCS of 10-30dB can be obtained [7].

It is well known that unwanted reflection of radar signals from the moving blades of a wind turbine installation can cause Doppler-induced and other target tracking errors and this situation becomes particularly important when the installation is sited near to the approach path of an airport. Although some of these deleterious effects may be tackled in the radar signal processing software, it may still be necessary to seek additional amelioration measures in the form of modifications to the electromagnetic scattering properties of the wind turbines and in particular the blades since it is their rotation which is the source of the problem. Conventional techniques for modifying the radar scattering characteristics of an object involve either shape change or the use of radar absorbent materials (RAM). Clearly the former is unacceptable in the present application since the shape of the turbine blades must be determined solely by aerodynamic considerations. For any RAM solution, the fundamental issues to be resolved will centre on absorber bandwidth, material thickness and weight. Clearly any acceptable RAM must be of the structural type; nevertheless, the trade-off between good absorber performance and minimum thickness and weight is still difficult to optimise. Simple replacement of passive RAM by a PSS will not of itself offer any advantage in terms of improved absorption characteristics but the PSS offers a way of either altering dynamically the Doppler shift produced by the rotating blades or of labelling the radar signals reflected from a particular turbine or blade with a unique binary Doppler code. This might then enable the tracking radar to distinguish such a signal from that produced by an aircraft (and hence reject it) or to identify which turbines in a farm are causing the most disruptive reflections. To illustrate this technique, Figure 3 shows the measured Doppler spectrum reflected from a 10 GHz model of a wind turbine whose blades are covered by a PSS layer. In this test, the blade hub was uncoated and hence the low frequency Doppler components were not suppressed by the PSS [8].

The above discussion has concentrated on planar PSS topologies, but the technique has also been shown to be effective on curved surfaces. Furthermore, non-planar geometries also offer the possibility of dynamic control of scattering not only in the time and frequency domains but also in the spatial domain [9].

Like its passive Salisbury screen counterpart, a single layer PSS is only effective over a fairly limited bandwidth (although the effects of diode reactance can ameliorate this to some extent). Increased bandwidth and functionality can be obtained, however, by increasing the number of active FSS in the structure [10],[11].

Conclusions

Although such a short review cannot be comprehensive, nevertheless it is apparent that the PSS offers an attractive combination of simplicity in construction and versatility in application in both the civil and defence fields.

References

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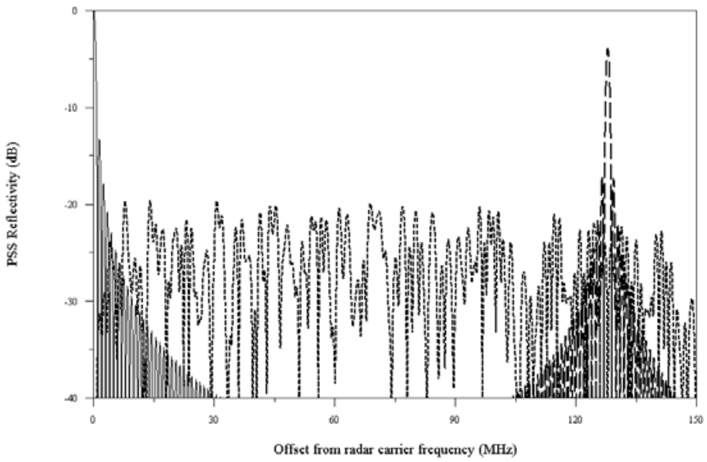

Figure 1 Predicted spectra of incident radar signal, PSS reflected signal with regular square wave switching and PSS reflected signal using 256 bit code

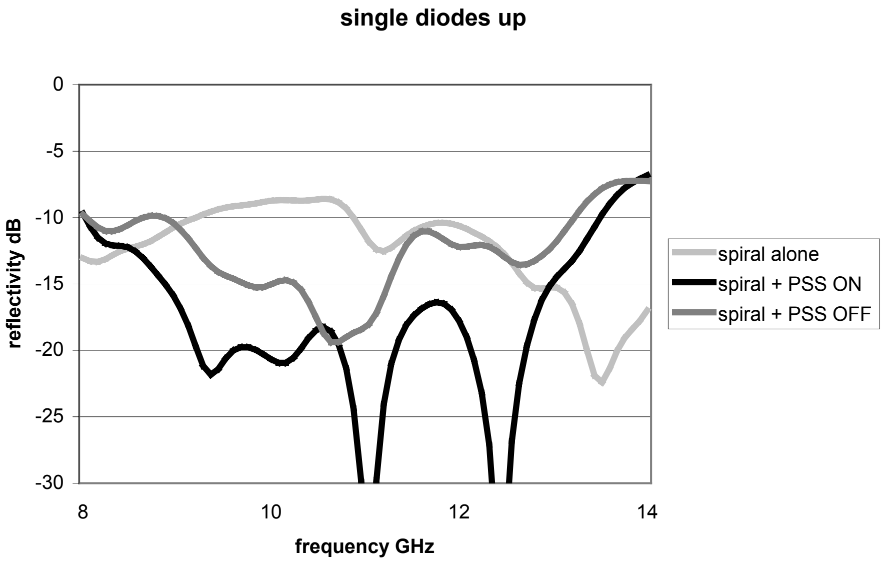

Figure 2 Measured reflectivity response of cavity-backed spiral antenna with PSS boundary

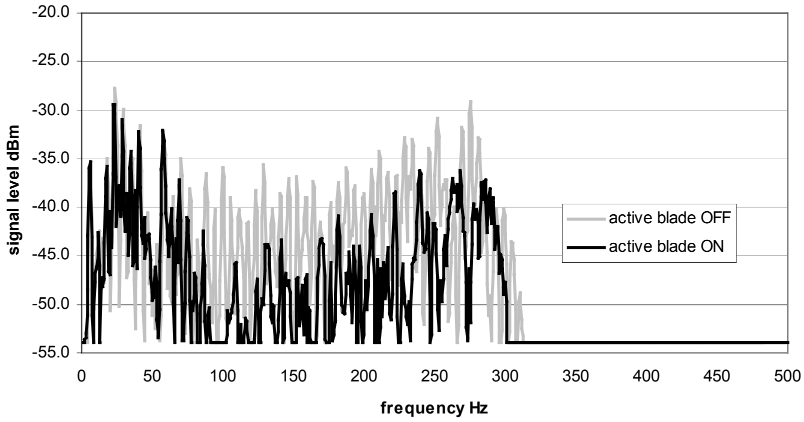

Figure 3 Measured reflected Doppler spectrum from PSS coated wind turbine