Progress In Electromagnetics Research Letters, Vol. 1, 1–8, 2008

A NOVEL TECHNIQUE FOR IMPROVING THE PERFORMANCE OF SALISBURY SCREEN

A. A. Abdelaziz

Faculty of Engineering
Misr International University (MIU)
Cairo, Egypt

Abstract—The most common and simple structure to reduce the level of the reflected power from a metallic surface is the single layer structure known as Salisbury screen which is a sheet of porous material impregnated with graphite and spaced a quarter-wavelength off a metallic backing plate. The main disadvantage of this mechanism is the narrow frequency bandwidth. Many techniques have been reported to improve the working frequency bandwidth but with some degradation in the other technical properties of the overall structure. In this paper a novel technique has been introduced based on a spatial kind of material called circuit analog screen. Theoretical analysis shows that the bandwidth of the reflected power will be improved if the graphite sheet of Salisbury screen has been loaded by circuit analog screen with spatial geometry with spatial parameters.

1. INTRODUCTION

One of the oldest and simplest types of radar absorbing devices is represented by Salisbury screen [1, 2] which is a resonant absorber technique working in a narrow frequency bandwidth. The bandwidth of this device can be increased [3] by cascading several sheets, one behind the other and separated by spacer. However, additional sheets require additional spacers, and the thickness of the device increases. Another technique has been reported in [4] with the main concept of that the inclusion of circuit analog screen into the radome will increase the wave absorption bandwidth. In this paper, a novel technique is presented for improving the performance (bandwidth) of Salisbury screen by loading the resistive sheet of Salisbury screen with circuit analog screen in the form of square loop array sprayed on thin plastic sheet. The analysis of the circuit of analog screen is based on equations given by Marcuvitz [5] for impedance of periodic arrays of thin continuous conducting strips. The theoretical results of the novel technique show that the working bandwidth of the reflected waves has been improved more than twice of the old one without any degradation of the original performance.

2. NORMAL INCIDENCE SCATTERING FROM FLAT DIELECTRIC MULTILAYER

Calculation of the reflected power of a normally incident plane wave from an infinite flat multilayer structure is a straightforward problem involving application of boundary conditions derived from Maxwell's equations to the general solution for the electric and magnetic fields in each layer. The basic structure consists of a finite number of dielectric layers stacked against a metallic backing plate as shown in Figure 1. Calculation of reflected power in dB of normally incident plane wave for m layers is given by:

$$|R| = 20\ \log_{10}\left|\frac{P_m}{U_m}\right| \tag{1}$$

where U_m, P_m are the amplitudes of forward and backward propagation waves and equal to (2):

$$\begin{aligned} U_m &= \frac{e^{-jk_m x_n}}{2Y_m}\left[U_n(Y_m+Y_n+Y_m^s)e^{jk_m x_n}+P_n(Y_m-Y_n+Y_m^s)e^{-jk_m x_n}\right] \\ P_m &= \frac{e^{jk_m x_n}}{2Y_m}\left[U_n(Y_m-Y_n-Y_m^s)e^{jk_m x_n}+P_n(Y_m+Y_n-Y_m^s)e^{-jk_m x_n}\right] \end{aligned} \tag{2}$$

where $m = n + 1$;
Y_m is the normalized, to Y_0, layer intrinsic admittance and is given by: $Y_m = \sqrt{\dfrac{\varepsilon_{r_m}}{\mu_{r_m}}}$.
Y_0 is the free space admittance equal to $1/377\,\Omega$.
Y_m^s is the normalized, to Y_0, sheet admittance and given by: $Y_m^s = G_m + jB_m$.

3. SINGLE LAYER WITH CONDITION OF MINIMUM REFLECTED POWER

Consider only one covered dielectric layer, see Figure 1, with $\varepsilon_r = \mu_r = 1$ and $k_2 = k_1 = k_0$, free space wave number, then Equation (2) will be:

$$U_2 = \frac{e^{-jk_0 x_1}}{2}\{[2 + (G_1 + jB_1)]e^{jk_0 x_1} - (G_1 + jB_1)e^{-jk_0 x_1}\}$$

$$P_2 = \frac{e^{jk_0x_1}}{2}\{-(G_1+jB_1)e^{jk_0x_1} - [2-(G_1+jB_1)e^{-jk_0x_1}]\} \quad (3)$$

where $P_1 = -U_1$ for a metallic backing at $x = 0$.

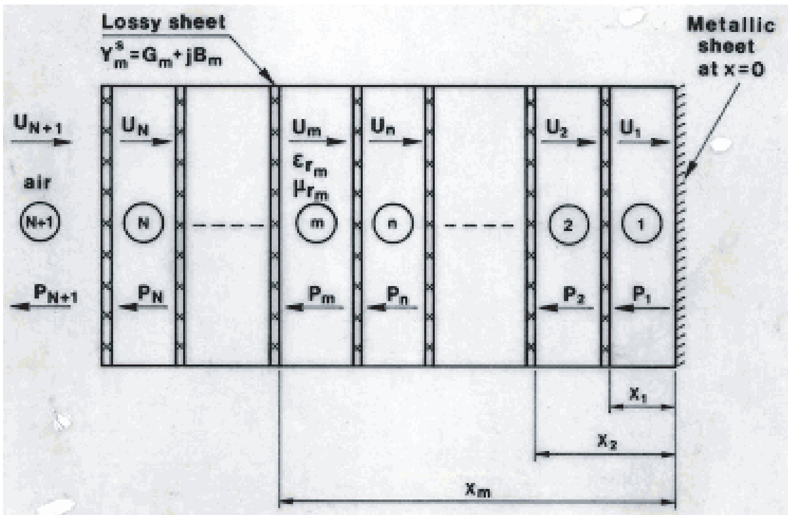

Figure 1. Configuration of multi-covered layer.

From Equations (1) and (3), the reflected power will be minimum if P_2 is forced to be zero, and P_2 will be zero if $G_1 = 1$ and B_1 satisfies the following condition: $0 = -(1+jB_1)e^{jk_0x_1} - (1-jB_1)e^{-jk_0x_1}$, after some manipulations:

$$B_1 = \cot(k_0x_1) \quad (4)$$

Equation (4) gives the value of susceptance B_1 of the loaded lossy sheet for minimum reflected power and is plotted as shown in Figure 4(a), the dotted curve, for separation distance $x_1 = 7.5\,\text{mm}$ and frequencies from 1 up to 18 GHz.

4. INVESTIGATION OF A CIRCUIT ANALOG SCREEN WHICH SATISFIES THE CONDITION OF MINIMUM REFLECTED POWER

The values of susceptance B_1 for minimum reflected power given by Equation (4) can be represented by a circuit analog screen in the form of a series of inductive and capacitive elements. Circuit analog screen is a spatial material utilizes lossy material deposited in geometric patterns on a thin lossless film. The geometry of the pattern controls the effective inductance and capacitance. Thus, the layer can be tailored to specific values of inductance and capacitance and its performance can be analyzed in terms of lumped elements. An infinitely extended plane grating, shown in Figure 2, formed by metallic strips of zero thickness with edges parallel or perpendicular to the electric field E and with normal-wave incidence has been analyzed by Marcuvitz [5]. The equivalent circuit's parameters, normalized values, are frequency dependent and are equal to [5]:

Inductive reactance; $\dfrac{X_l}{Z_0} = \dfrac{p}{\lambda}\left[\ln\csc\left(\dfrac{\pi s}{2p}\right) + \xi_1\right]$

where:

$$\xi_1 = \frac{1}{2}\frac{\left(1-\beta_1^2\right)^2\left[2\left(1-\dfrac{\beta_1^2}{4}\right)A_1 + 4\beta_1^2 A_1\right]}{\left(1-\dfrac{\beta_1^2}{4}\right)+\beta_1^2\left(1+\dfrac{\beta_1^2}{2}-\dfrac{\beta_1^4}{8}\right)2A_1 + 2\beta_1^6 A_1}$$

$$A_1 = \frac{1}{\sqrt{1-\left(\dfrac{p}{\lambda}\right)^2}} - 1, \qquad \beta_1 = \sin\left(\frac{s}{2p}\right) \tag{5}$$

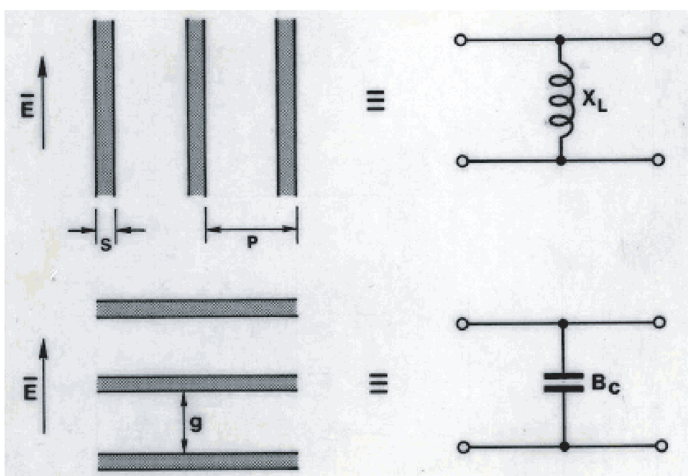

Figure 2. Metallic strips of zero thickness and their equivalent circuits.

And;

Capacitive susceptance; $\dfrac{B_c}{Y_0} = \dfrac{4p}{\lambda}\left[\ln\csc\left(\dfrac{\pi \mathrm{g}}{2\mathrm{p}}\right) + \xi_2\right]$

where:

$$\xi_2 = \frac{1}{2}\frac{\left(1-\beta_2^2\right)^2\left[2\left(1-\dfrac{\beta_2^2}{4}\right)A_1 + 4\beta_2^2 A_2\right]}{\left(1-\dfrac{\beta_2^2}{4}\right) + \beta_2^2\left(1+\dfrac{\beta_2^2}{2}-\dfrac{\beta_2^4}{8}\right)2A_2 + 2\beta_2^6 A_2}$$

$$A_2 = \frac{1}{\sqrt{1-\left(\dfrac{p}{\lambda}\right)^2}} - 1, \qquad \beta_2 = \sin\left(\frac{\pi g}{2p}\right) \tag{6}$$

The easiest way to represent the inductive-capacitive circuit equivalent to what is given by Equation (4) is to consider the square loop array as shown in Figure 3 which consists of the metal strips given in Figure 2. An Array of square-loops has been modeled [6, 7] based on equations given by Marcuvitz [5]. The equivalent circuit model of square-loop array is represented by a single series LC circuit shunted a transmission line. A computer program has been written to calculate the normalized values of a shunt inductive reactance (X_l) and capacitive susceptance (B_c) given by equations (5, 6) for different values of s, g and p shown in Figure 3. The solid curve in Figure 4(b)

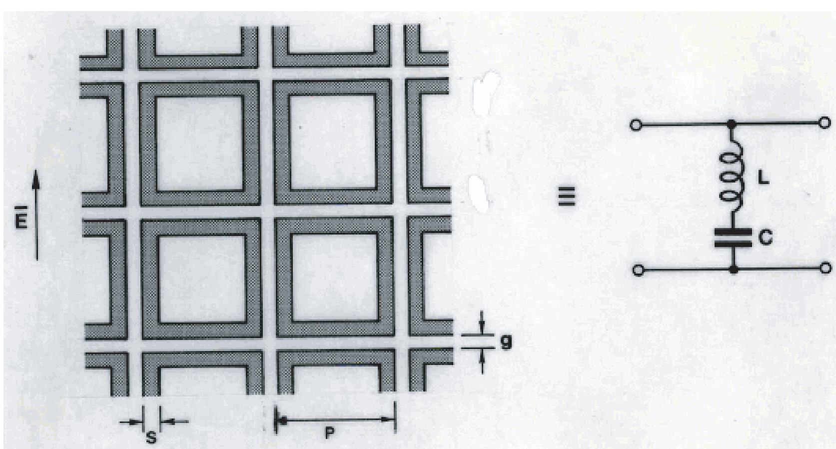

Figure 3. Element geometry of square loop array and its equivalent circuit.

shows the computed results of susceptance B of a lossless square-loop array with values $s = 2$, $g = 2$, and $p = 12\,\mathrm{mm}$ and frequency from 1 up to 18 GHz. The results are very near to that required from condition of minimum reflected power given by Equation (4).

5. CALCULATION OF THE REFLECTED POWER

To calculate the reflected power from a single layer, see configuration given in Figure 1, for two different cases given as:

Case (1): Single layer covered with only resistive sheet.

Case (2): Single layer with a cover consists of a resistive sheet loaded by the square-loop array shown in Figure 3.

A computer program has been written based on Equations (1, 2) to calculate the reflected power in dB with the parameters given in Table 1.

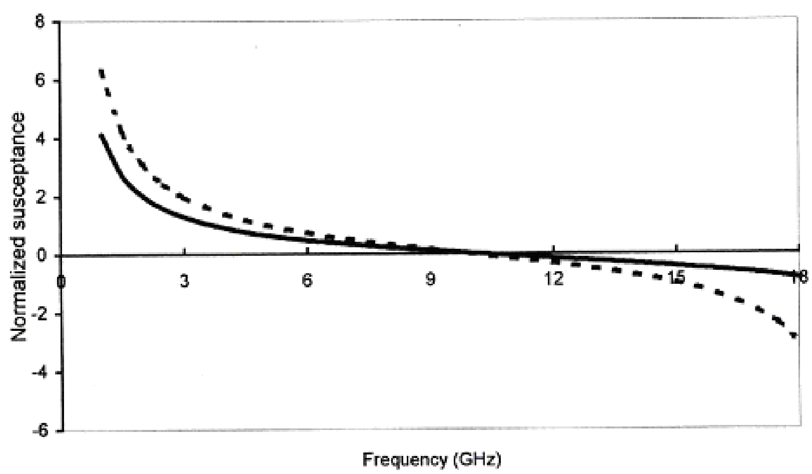

Figure 4. Susceptance (B) versus frequency for two different cases: (a) - - - - - Condition for minimum reflected power given by Equation (4), (b) —— Square loop array shown in Figure 3 with $s = 2$, $g = 2$, and $p = 1$.

The computed results are shown in Figure 5. The dotted curve for the case of resistive sheet only and has a minimum reflected power $\cong -57\,\mathrm{dB}$ at central frequency equal to 10 GHz, relative to $x_1 = \lambda_0/4$, with frequency bandwidth of the reflected power equal to 7.5 GHz

Table 1. The parameters of single layer for the configuration of Figure 1.

Parameters	**Case (1)**	**Case (2)**
$Y_1^s = G_1 + jB_1$	$G_1 = 1,\ B_1 = 0$	$G_1 = 1,\ B_1$ given by Equations $(5, 6)$
$x_1\,(\text{mm})$	7.5	7.5
$\varepsilon_{r1} = \mu_{r1}$	$1, 0$	$1, 0$

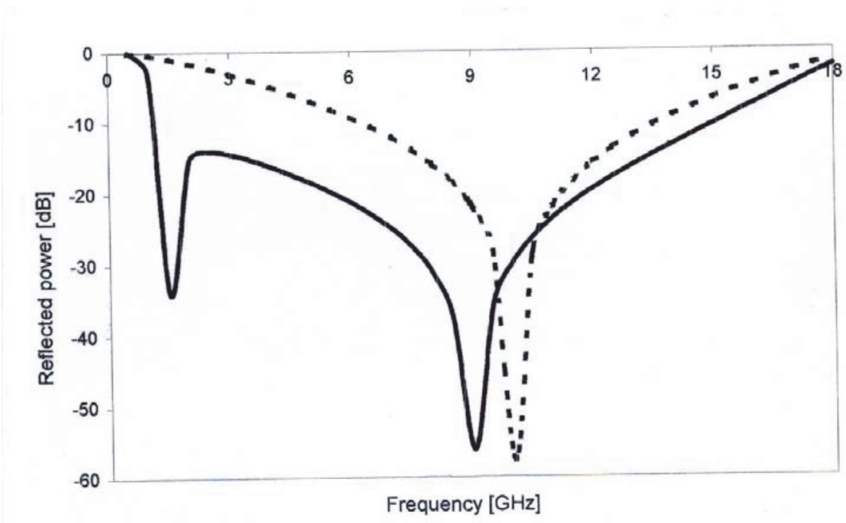

Figure 5. Reflected power from single layer, configuration of Figure 1, for two different cases: (a) - - - - - Only resistive sheet with $G_1 = 1$, $B_1 = 0$, (b) —— Resistive sheet loaded by square loop array shown in Figure 3.

for threshold level of reflected power equal to 10 dB. For the case of resistive sheet loaded by square-loop array, the minimum reflected power is $\cong -56$ dB at central frequency equal to 9 GHz with frequency bandwidth equal to 14.5 GHz for the same threshold level. These results mean that the loaded square-loop array increases the working bandwidth twice of the normal Salisbury screen with a shift of the reflected power null. The frequency shift means a reduction in the physical separation distance x_1 which means a good advantage for reducing the thickness of the working device.

6. CONCLUSION

The new structure of Salisbury screen which is loaded by circuit analog screen has been analyzed to find out the optimum condition for minimum reflected power in terms of the susceptance of the loaded sheet. A square loop array sprayed on thin plastic sheet has been used as an equivalent to the susceptance investigated for minimum reflected power. The calculated results of the reflected power from the novel technique show an improvement in the working bandwidth of the reduced reflected power of Salisbury device more than twice without any penalties in the weight or thickness.

REFERENCES

1. Salisbury, W. W., "Absorbed body of electronic waves," U.S. Patent No. 2,599,944, June 10, 1952.
2. Gustafsson, M., "RCS reduction of integrated antenna arrays with resistive sheets," *Journal of Elec. Waves and Application*, Vol. 20, No. 1, 27–40, 2006.
3. Knott, E. F., J. F. Shaeffer, and M. T. Tuley, *Radar Cross Section*, Artech House, London, 1993.
4. Henderson, A., A. A. Abdelaziz, and J. R. James, "Investigation of interference suppression radome for microstrip arrays," *Proceeding ICAP*, Edinburgh, 1993.
5. Marcuvitz, N., *Waveguide Handbook*, Peter Peregrinus Ltd., London, 1986.
6. Langley, R. J. and E. A. Parker, "Equivalent circuit of square loops," *Electronic Letters*, Vol. 18, No. 7, April 1982.
7. Langley, R. J. and E. A. Parker, "Double-square frequency selective surfaces and their equivalent circuit," *Electronic Letters*, Vol. 19, No. 17, August 1983.