Time - Domain (Transient) Anlysis of Capacitve Jaumann Absorbers

Ahmad CHELDAVI and Mahmoud KAMAREI

Iran University of Science and Technology

E.C.E. Dep. University of Tehran, Tehran, Iran

Fax : (+98) 21-8778690 Tel : +98-21-8027756

Email : Cheldavi@ece.ut.ac.ir

ABSTRACT

Capacitive Jaumann Absorbers (C.J.A.) are widely used as electromagnetic wave absorbers in several applications, because in addition to bandwidth expanding, they reduce the spacing between sheets for specified bandwidth.

In this paper the principle of an exact time-domain analysis of N-sheet C.J.A. and an optimum design for N (arbitrary)-sheet capacitive jaumann electromagnetic (EM) absorber, using genetic algorithm will be presented. This algorithm is a random optimization method based on the genetic relation in the human being. We show that by using this algorithm and without imposing the double-notch design criteria the bandwidt of one or two-sheet C.J.A. can be expanded even more than 108% shown by knott[1]. We also show that our results approaches knott's results when we restrict the charateristic impedances and lengthes of the lines to vary within a very short range. one, two and three-sheet C.J.A. are designed. The only restriction used is about the meaningful range for the design variables. The goal of this algorithm is to impose arbitrary restriction on the range of the variation of the variables.

Finally, we obtain a 20-dB attenuation bandwidth more than 145% for one-sheet, 173% for two-sheet (compare with 108% obtained in [1]) and 193% for three-sheet capacitive jaumann EM absorbers, with some acceptable short range for the variables.

We design the one-sheet and two-sheet capacitive jaumann absorbers at low frequency and the three-sheet at high frequency.

The 20-db attenuation bandwidth obtained for the one-sheet and two-sheet capacitive jaumann absorbers are respectively, from 10 to 77 MHz and from 4 to 61 MHz.

For the three-sheet capacitive jaumann absorber the 20-db attenuation bandwidth obtained is from 0.8 GHz to 280 GHz.

INTRODUCTION

The objective of the stealth technology is to reduce the radar cross section (RCS) of the targets to a level where the radar receiver cannot detect the target [2].

There are four techniques for radar cross section reduction [2]. Shaping, radar absorbing materials (RAM), passive cancellation and active cancellation. The objective of shaping is to return the incident waveform in a direction other than the radar line-of-sight, while the objective of RAM is to convert the incident EM energy to the heat. The last two methods for RCS reduction are rarely used now.

There are four major types of EM absorbers [8]; 1) resonant absorbers which are based on the principles of salisbury or screens [2]; 2) ferrite absorbers, with a typical low frequency and small bandwidth application; 3) carbon-loaded foam pyramid absorbers used in anechoic chambers; 4) absorbers with gradually changing properties to reduce surface current which cause radiation at discontinuties such as sharp edges.

Salisbury screen may be the simplest and earliest EM absorbers which consists of a single

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resistive layer spaced a quarter-wavelenth from the metal backing plate. In this absorber one can obtain a zero reflectivity in the center frequency but the 20-db attenuation bandwidth in the reflectivity coefficient cannot excede 25% in any way.

We may expand the bandwidth by using additional capacitive sheets, creating capacitive jaumann absorber. Sheets with series capacitance are widely used because in addition to bandwidth expanding, they reduce the spacing between sheets for specified bandwidth. The optimum design of N-sheet (N is arbitrary) jaumann absorber mathematically is very difficult, because for N-sheet jaumann absorber we have 4N variables for optimization.

By optimum design we mean at list a most 20-db attenuation bandwidth, the shortest spacing between sheets, and a simple design method. We use random (genetic) algorithm for our purpose, and we show that (by imposing a reasonable range restriction on every variable, instead of other numeric restrictions on the reflection coefficient) bandwidth can be expanded almost linear (before some saturation level) with the range dimension.

THEORY

In this paper we use the transmission line simulation for the capacitive jaumann absorber (CJA) structure as shown in Fig 1. Where R_n and C_n are the resistance and capacitance of the N-th sheet, and R_g is the internal impedance of the source. Because the source is in free space, we always set $R_g=120\pi$. According to references 3 and 4, for the first step in Fig.1 we have the following equation :

$$v(0, t) = v^{+}(0, t) + v^{-}(0, t), \tag{1}$$

in which v is the voltage and (+) and (-) superscript represnt the incident and reflected waves respectively.

We can also write (1) as :

$$v(0, t)=v^{+}_{1}(0, t)-k_g(t)v^{+}(0,t-\frac{2d}{v}) -v^{+}(0,t-\frac{2d}{v}) \tag{2}$$

in which $k_g(t)$ is the reflection coefficient in the source terminal and $v^{+}_{1}(0, t)$ is the part of the incident wave caused by the source (and not from the multiple reflections). The major important work of this paper is to find an exact equatin for $k_g(t)$, because $k_g(t)$ is a contemporarily function of the load and voltage across the source terminal [3, 4].

Because of the multiple wave reflections in the line, we must consider all incident and reflected waves in the line for a given time, and then simultanuosly find the $k_g(t)$ for that time. This can be done by defining bounce matrix for the line.

Such a bounce matrix is based on the bounce diagram. Using this matrix, one can find all propbable bounces and their lenghts between the source and load, or midline terminals in the bounce diagram in each instance. This matrix can be obtained by computer using simple algorithms.

Using bounce matrices we can find the voltage across the line and $k_g(t)$ simultanously. The load is a short circuit (metal backing plate).

To obtain a wideband obserber the problem now converts to a wideband matching problem between Z_g and short-circuited load, using 4N variables :

(βd), Z_{0i}, R_i, C_i for i=1, 2, ... N.

β is the wave number, d is the length of the line, z_0 is the charachteristic impedance of the line and finally R and C are the resistance and capacitance of the series RC model of the sheet.

To reduce the voltage reflection coefficient seen by the source, we must choose 4 optimal variables for every layer. This purpose, instead of imposing a restriction on the reflection coefficient function, such as single notch[5], or double notch[1] design, we impose a range restriction which is acceptable for all variables, and we allow the variables to vary freely within this range. As an optimization role we use an special genetic algorithm introduced in reference 6.

The admitance looking just after each sheet is

$$Y_i=B_i+Y_{0i}\cdot\frac{Y_{i-1}-jY_{0i}\tan(\beta d)}{Y_{0i}+jY_{i-1}\tan(\beta d)_i} \tag{3}$$

for i=2,3,..,N , and for i=1

$$Y_1=B_1-jY_{01}\text{cotg}(\beta d)_1 \quad (4)$$

in which B_i an Y_{0i} are respectively the admitance of the j-th sheet and the charactristic admitance of the i-th line. To search for the global minimum(s) of the reflection coefficient we have to minimize

$$|T| = |\ T[(\beta d)_i, Y_{0i}, R_i, C_i)]\ |$$

$$= |[(Y_g-Y_N)/(Y_g+N_N]| \quad (5)$$

by choosing of the 4N variables.

This complicate formula has several local and probably some global minimums, but some of them do not have physical meanings. So we search for physical minimums which lay in the proper range, such as,

$$k(\beta d)_0<(\beta d)_i<(2-k)(\beta d)_0$$

$$mZ_{00}<Z_{0i}<(2-m)Z_{00}$$

$$IR_0<R_i<(2-1)R_0$$

$$pC_0<C<(2-p)C_0$$

for some reasonable d_0, Z_{00}, R_0 and C_0 (k, m, l and p are positive constants less than unity). By this restrictions we reduce the number of the local minimus in the specified range. After design of proper range for variables, we use the genetic algorithm for optimizatin.

Optimization Using Genetic Algorithm

There are several genetic algorithms which are widely used for optimizing problems involving many variables. For our porpuse we used an special genetic algorithm developed in reference 6. In this algorithm we force the function $|T|$ to be less than -20dB over the entire speciefied region of the spectrum without any restriction about the other frequencies, while keeping the variables in the acceptable range mentioned above.

Results and Conclusions

Genetic algorithms are random optimization methods, so we cannot expect the reasonable results within a short peroid of iterations. We must allow the algorithm to search freely with very large number of iterations, because the convergence to the theoretical optimum point for these algorithms reaches when the iterations approach infinity.

Indeed, the optimum design do not find it's proper meaning until we introduce the restrictions for the range of the variables and frequency band. In other word for every range of the variables and for every frequency band we have a special or probably several optimum point(s).

We saw the optimum design for two sheet capacitive jaumann absorber cannot give us bandwidth more than nearly 108% when we restrict the Y_{0i} and $(\beta d)_i$ within a very short range with this restriction, we saw two notchs in the reflection coefficient function, and this is exactly the double notch design procedure used by knott [1]. So we may call the knott's double notch design, an optimum design with fixed $(\beta d)_i$ and Y_{0i}.

As an important result, we saw that maximum 108% bandwidth, which is available for several spacings between two sheets, depends on the different choices for Y_{01} and Y_{02}. We also optimized one- two- and three-sheet capacitive jaumann absorbers, and the results are shown in tables 1, 2 and 3.

In the first two tables β was calculated for f=30 MHz and in the last table β was calculated for f=5 GHz.

As shown in Figures 2, 3 and 4, the optimum percent bandwidth for one, two- and three-sheet capacitive jaumann absorbers are more than 145%, 173% and 193% respectively, We also saw that when the range of the variables increases we can still find better point and larger bandwidth (expected result).

References

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Table.1

Lay.No	βd *(rad)*	Y_0 *(mho)*	R *(Ω)*	C *(PF)*
1	0.325 π	0.0017	50.57	754.84

Table.2

Lay.No	βd *(rad)*	Y_0 *(mho)*	R *(Ω)*	C *(PF)*
1	0.366 π	0.008	58.56	214.5
2	0.436 π	0.0016	50.37	3219.3

Table.3

Lay.No	βd *(rad)*	Y_0 *(mho)*	R *(Ω)*	C *(PF)*
1	0.493 π	0.0038	178.6	350.2
2	0.343 π	0.0007	140.68	543.16
3	0.84 π	0.0073	78.68	1424.4

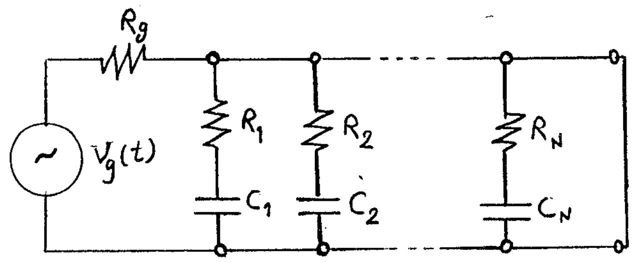

Fig.1

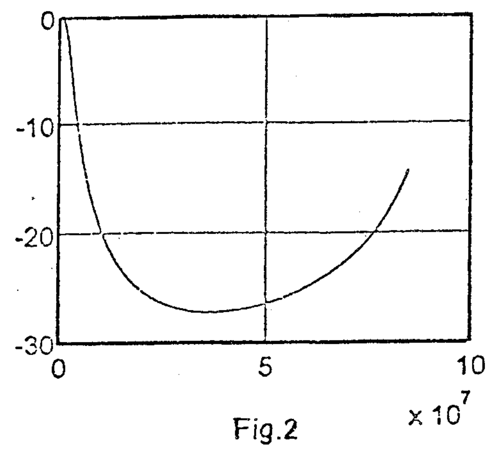

Fig.2

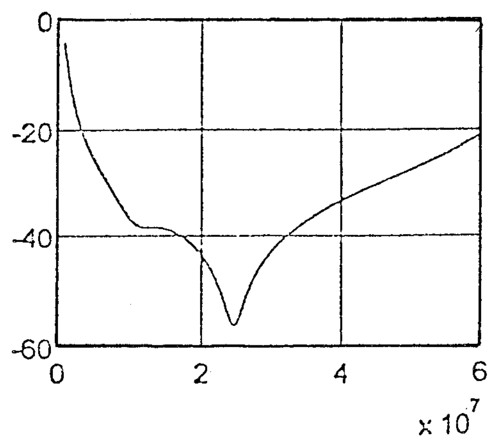

Fig.3

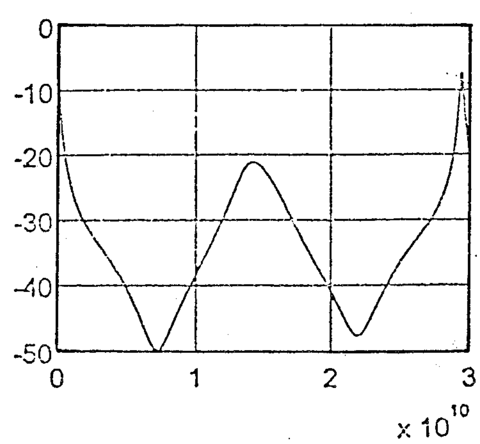

Fig.4