Catalyzed Mechanism for Microwave Absorption in Composite Barriers

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Abstract

A series of two-layered composite barriers filled with (10% carbon black) were produced, with their second layers loaded with foreign dispersion acting in aid of the microwave absorption process. Fixed weights of chopped copper wires with lengths (1,3,5) mm were dispersed in the above mentioned barriers. The resulting behavior indicates that these catalyst dispersion played a very useful role in enhancing the absorption of the barrier. Moreover, certain wire lengths exhibited an optimum behavior at various frequencies, suggesting that these wires act as short dipole antennas which convert the microwave signal into a leaked current. Mixing various wire lengths yielded a (100% bandwidth covering the whole of the X-band fore reflectivity level less than –11dB). Also various concentrations of AL-powders were dispersed in these second layers and an optimum concentration exhibited a low reflectivity level over the whole X-band. Intermixing of wires and powders produced a rather poor behavior suggesting that this might be due to the metallic over exceeded presence in the barrier.

المستخلص

حُضِرت حواجز متراكبة من طبقتين محشوة بتركيز(١٠%) من مسحوق الكاربون الأسود.حيث إن الطبقة الثانية طعمت بمواد إضافية مشتتة لعبت دوراً محفزاً في عملية امتصاص الموجات الدقيقة.كذلك تم تطعيم الطبقة الثانية من الحاجز المتراكب بأوزان ثابتة من الأسلاك النحاسية المقطعة بأطوال مختلفة(١,٣,٥)مليمتر.التصرف الناتج أظهر إن المشتتات المحفزة لعبت دوراً مفيداً جداً في تعزيز امتصاص الحاجز للموجات الدقيقة.من ناحية أخرى, أطوال السلك في الحاجز المتراكب اظهرت تصرفاً مثالياً عند ترددات مختلفة من الحزمة مما يوحي بأن الأسلاك عملت كهوائي ثنائي قصير يقوم بتحويل إشارة الموجات الدقيقة إلى تيار متسرب داخل الوسط.تم الحصول على انعكاسية اقل من -١١ ديسيبيل عند خلط أطوال مختلفة من السلك النحاسي وبعرض نطاق ترددي واسع ضمن الحزمة.أضيفت تراكيز مختلفة من مساحيق الألمنيوم للطبقة الثانية من

الحاجز المتراكب, عند تركيز معين لمسحوق الألمنيوم اظهرت انعكاسية قليلة على كل الحزمة الترددية. الخلط لمادة مسحوق الألمنيوم وأسلاك النحاس أبدى انعكاسية عالية بسبب زيادة نسبة المعدن في الحاجز.

1. Introduction

Radar wave absorbing barriers have become a center of attraction for many research groups, since the declaration of the stealth aircraft [1]. Prior to that the application has been mainly concerned with echoless chambers and few other applications[2]. The main factor affecting the detection capability of a certain airborne target is it's Radar Cross Section (*RCS*) at that frequency band. This is decided heavily by the geometry of the target, specially the overall size and the details of the shape. The (RCS) of target may be reduced by coating the target with Radar Absorbing Material (RAM)[3] .   A number of materials have been investigated and more may be still under investigation .The menu included the carbon black family [4], the family of ferrite and other chemicals [5]. These have been used in the form of simple (one-layer) barrier, a complex combination of layers [6,7] either of the same type but with different concentrations or different materials. The point of major importance is the nature of the material like its absorbance, it's dielectric constant, permeability, ε and μ respectively. Moreover, there are some criteria to be considered when a barrier is being developed, which are the reflectivity minimal and the bandwidth of the reflectivity. Their have been some work on complex barriers which suggested that the multilayer barrier should have a minimum value of ε or μ at the inter layer boundary in order to make sure that the incoming microwave penetrates the barrier system. This would enhance the probabilities of absorbance loss of the microwave. This in fact has lead to the idea of using some foreign bodies imbedded within the absorbing medium, in order to stop the penetrated wave from leaving the barrier very quickly, or to transform the wave signal into some other form of power which may be deposited with the boundaries of the barrier.

The efforts of researchers were concentrated on two goals. The first goal, is reducing the reflectivity to the optimum level. The second, is reducing the thickness of the barrier and arriving at the painting technique. Unfortunately, these efforts were often unpublished and were top secret because they are used in military applications such as the stealth technology in fighter aircrafts.

However, we can mention some of these efforts .A multilayer barrier made of four layers of composted ferrites was investigated experimentally [5]. This completed absorber has a performance of about -7 to -16 dB reflection loss over (8 to 18 GHz).The computed and measured reflection loss curves differ by about ±2dB in a way. The total thickness of four layers was 20 mm. A method of reducing the thickness of a ferrite absorbing wall and controlling the matching frequency characteristics by applying DC magnetic field, H_{dc} , perpendicularly to microwave magnetic field [8].By combining rubber with carbon and ferrite, a material having dielectric and magnetic losses is obtained[9].This material shows good absorbing characteristics when used in a single-layer structure backed with a conductor. The best absorber characteristics among the investigated combinations were obtained when the ratio of ferrite was equal to the ratio of carbon black in the hybrid single layer. In the C-band, its relative bandwidth in a single layer structure is up to 4.5 times wider than of nonmagnetic lossy dielectric material of the same thickness. Moreover, a multi-layer barrier made of six layers combined from simple layer (ferrite-epoxy) and hybrid layer (carbon and ferrite epoxy) was investigated experimentally [10],the total thickness of multi-layer structure was 3mm. The absorption performance is considered to be good results in 6.5 to 7.5 GHz for reflectivity level less than (-10 dB).From the results obtained that absorption increases when the thickness of layer increases.

It is aimed by this work to develop a new type of barrier not only of complex nature but also of hybridized layers. By doping these layers with absorption aids (or *catalysts*) like wires or metal powders in order to modify the mechanism of absorption or looseness of the material.

2. Experimental techniques

The basic matrix of the barrier consists of solid Novolak, which is powdered in the fine particulates, mixed with the proper catalyst and heated to $100C^o$ until the mixture shows signs of fusion. The mixture is then crushed and mixed with appropriate amount of (*10 % carbon black*) and *catalysts (*Aluminum powder, wires Copper) fillers. The homogenized mixture is then hot pressed (10 ton) at 150 C^o for 30 minutes. The resulting disk-shaped specimen is then machined into rectangular cross section, with dimensions to suit the inner tube of the wave-guide[11].Two types of barriers were developed those of layer (simple), and those which consisted of multilayers each consists of different filler concentration.

The network analyzer as shown Figure(1) is characterized by high accuracy, high speed measurements, in addition to the scanning capability of the frequency band of interest, which included the X-band. A (HP8510B) computer is interfaced with the above analyzer, and prior to any use the whole system is usually calibrated. Two measurement assembles were used, a two port and a single port arrangement as shown in Figure(2) and Figure(3) respectively .In case of the one port arrangement, both the transmitter and receiver are located on one end of the waveguide tube. The other end facing a metal sheet which is considered to be short circuit, because it is a perfect reflector. Normally, the specimens under investigation placed in between the short circuit plate and tightly filled under inside the waveguide opening.

This arrangement in fact is considered the nearest to the real situation. Moreover the scattering of microwaves at the edge of the inner tube of waveguide and specimen is expected to enhanced the reflectivity readings of the barrier. This of course is not applicable in actual practical situations ,which makes the waveguide results to be considered as modest in this scheme of analysis. The following formula of wave conservation is valid:

$$R^2+A^2=1 \qquad (1)$$

Where

R=reflection coefficient.

A=Absorption coefficient.

In the second scheme of analysis (two-port arrangement) the waveguide tube openings are individually blocked by transmitter on one side and a receiver on the other side. In this scheme of analysis the following formula is valid

$$R^2+A^2+T^2=1 \qquad (2)$$

Where

T=Transmission coefficient

The advantage of this arrangement is that it analyses the fine details of the interaction where the above three components of the interacted wave are immediately determined(R and T are measured ,A is calculated from (2)).

3. Results and discussion

A two-port arrangement was used to investigate the details of the microwave interaction with composite barriers between resin matrix filled with various concentrations (0-50%) of carbon black. From figure (4),it can be seen that the carbon black filler seems to offer an optimum effect at (10%) presence, where the overall reflectivity is minimum and the absorption is found to be maximum. In order to design and control the absorption process it might be interesting to use some looseness-aid or catalysts to enhance the absorption .These added inclusions are thought to force the penetrated microwave to travel in a new region before leaving the barrier, so that a complex barrier was arranged in such a way as shown in the Figure (5). A first layer (3mm thick) containing (10%) carbon black is followed by a second layer of the same nature and thickness, but further composited by dispersing small amount of chopped copper wires (50μm diameter). The length of these wires was chosen to be (1,3,5mm) each was dispersed in separate barriers. Each complex barrier contains in its second layer a total weight of (0.5gm) of copper wires, which forms about (10 wt.%) of the second layer. The results of measurements made on these complex wire-dispersed barriers are shown in Figure (6). The behavior exhibited in this figure suggests that the presence of the dispersed wires have modified the behavior of a (6mm thick.) composite barrier containing (10%) carbon black filler only. Moreover, the modification reflected upon the bandwidth of the reflectivity level in a way that attracts attention. Moreover, it may also be noticed that the overall reflectivity loss seems to be affected by a certain correlation, between the length of the wire and the frequency of the penetrating wave. This may be further clarified by the values listed in Table (1) below.

Table(1).Relationship between catalyst wire length and wavelength.

Freq. GHz	*Reflectivity level dB*			*Length of wire / λg*		
	1mm wire	*3mm wire*	*5mm wire*	*1mm /lg wire*	*3mm /lg wire*	*5mm /lg wire*
8	-5.5	-8	-11	1 /67.4	1 /22.4	1 /13.4
9	-9	-7	-9	1 /49.4	1 /16.4	1 /10
10	-11	-10.5	-3	1 /40	1 /13.3	1 /8
11	-16	-9.75	-3.5	1 /34.2	1 /11.3	1 /6.8
12	-12.5	-10	-4	1 /30	1/10	1 /6

Here, it is obvious that the overall reflectivity level depends explicitly on the length of the dispersed wires. The (5mm) wire seems to enhance the absorption of the composite barriers at the lower end of the frequency range.

On the other hand, the (3mm) and the (1mm) dispersed wire seem to enhance the absorption at the higher frequency range of the X-band. This in fact raise a question about the relation between the wire length and the wavelength of the penetrated microwave. This may in fact be clarified by the deduced correlation between the length of the wire and λg (wavelength inside the waveguide), also listed in the Table (1).

It was noted that a maximum absorption is exhibited when the ratio of (wire length / λg) is about (1 /13.4).When this is converted into the case of free space the ratio of (wire length / λo(wavelength in free space)) is found to be very near to (1/10) which represents the case of *short* dipole antenna[12]. On the other hand, the (1mm) wire lengths did not conform to this hypothesis, since the above mentioned ratio was deduced to be in the region of (1/34-1/40). However, this may be correlated with triple the wavelength of (21GHz) frequency, where it represents the resonance frequency of the short dipole antenna of (1mm) long wire. Hence, the overall behavior of the (1mm) wire may also be explained in terms of the short dipole antenna.

By looking back on Table(1) it is noticeable that the maximum value for absorption in the (1mm) wire dispersion is higher than those in the case of (3mm) and (5mm)-wire dispersion. This may be discussed in terms of the electric currents that may be conducted and leaked by the medium. Since the microwave signals received by the wires are converted into electric currents to be leaked into the medium. The number of the (1mm)-wire pieces present in the hybrid is higher than that in the case of (3mm) and (5mm) wire dispersions. Hence, this layer presence of wire pieces would represent an enhanced conduction capability. Moreover, shorter wires would pose lower total resistance to the passing current, which should result into the passage of higher currents. Therefore, the overall behavior of the hybrid layer would suggest that shorter wires would help the absorption mechanism more than longer wires. This may be reflected as an enhanced imaginary part of the dielectric constant[13].

The above discussion may lead to the fact that the first layer of this complex barrier is making a good or rather transparent to electromagnetic waves. Whereas, the second layer is acting as a resonator to this complex system[14].

From the above discussion it was interesting to investigate the effect of mixed lengths in the hybrid layer, which was realized by a complex barrier whose second layer contains a mixture of (1mm) and (5mm) wires in a total presence of (0.5 gm). Also a second method of mixing was realized where the wire's lengths ranged between (1-5mm), and in a total presence of (0.5 gm).

Test results shown in Figure (7) indicate the effectiveness of this further hybridization, where the bandwidth in both cases was enhanced to cover 100% of the X-band fore reflectivity level less than (-11dB). However, the reflectivity values were lower in the case of a mixture of (1mm) and (5mm) only.

In a general comparison of all the above complex and hybridized barriers it might be worthwhile to consider the behavior of a (6mm) simple barrier containing (10% carbon black). The difference in the behavior may be considered as qualitative, and the complex / hybrid barrier may be considered as a different class of material all to gather.

Another type of hybridization to the second layer was made by dispersing various quantities (0.05gm-0.3gm) of aluminum powders. The aim was to investigate the effect of the fineness of the particles on the general absorption of the barrier.

Table(2).Frequency response of catalyzed complex barrier filled with AL-powder.

Freq.	*Reflectivity Level dB*			
GHz	*0.05gmAl*	*0.1gmAl*	*0.2gmAl*	*0.3gmAl*
8	-8	-11.7	-8.5	-8
9	-7.5	-11.5	-10	-9
10	-8	-11	-8	-4
11	-8	-11	-8	-3.5
12	-8.25	-11.2	-6	-3

The results are shown in Figure (8). and the measured values are listed in the Table (2). above. The barrier containing (0.1gm AL) exhibited an optimum reflectivity value at 10 GHz Fig(7). Beyond that, higher powder dispersion seemed to enhance the reflectivity level in an undesirable manner. The bandwidth of the optimum concentration was (100% over the X-band), with a reflectivity level less than (-11dB).The expected mechanism that governed the behavior of the powder dispersed barrier is thought to be that the aluminum particles act as scattering centers homogeneously dispersed throughout the second layer. These centers would act in a manner, which prolong the paths traveled by the penetrated microwave, thus enhancing the chance of these waves to be absorbed by the lossy medium. Hence, the powder is acting as a catalyst, which prolongs the time and length of flight of microwave within the barrier. It was thought to be quite interesting to mix both additive dispersion (wires and Al powders) in a single hybrid, and to study the behavior of this new type of hybrid. A new set of complex / hybrid barriers were produced and their mixed dispersion were fixed as listed in Table (3) . The general overall behavior was not up to the standard set by the wire-dispersed or the powder-dispersed barriers. However , the mixed dispersion containing (5mm wires and 0.1gm Al) gave modestly better results. This observed draw back might be due to the exceeded overall presence of metallic scattering centers, which could have affected the nature of the complex barrier negatively.

Table (3) .Frequency response of catalyst complex barriers doped with Cu-wire and AL-powder.

Freq. GHz	*Reflectivity Level dB*			
	1 mm wire + 0.1 gm AL	5 mm wire + 0.1 gm AL	1,5 mm wire + 0.1 gm AL	1-5 mm wire + 0.1 gm AL
8	-6	-7	-6	-7
9	-7	-10	-7	-6.5
10	-7.5	-11	-6.5	-6
11	-8	-7	-7.5	-5
12	-7	-7	-7.5	-7

4. Conclusions

Composite material filled with 10% carbon black has shown good behaviors to microwaves absorption. The principal of complexing the barriers resulted in an explicit broading of the frequency band and in enhancing the absorption in non linear manner. The wire catalysts acted as antennas, which received microwaves and then leak it to the lossy medium . The catalyst metal particles acted as scattering centers which prolonged the path of the microwave within the hybrid barrier. The catalysts metal-wires may also act mechanically to reinforce the composite matrix.

5. References

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Figure (1). Network analyzer HP8510B.

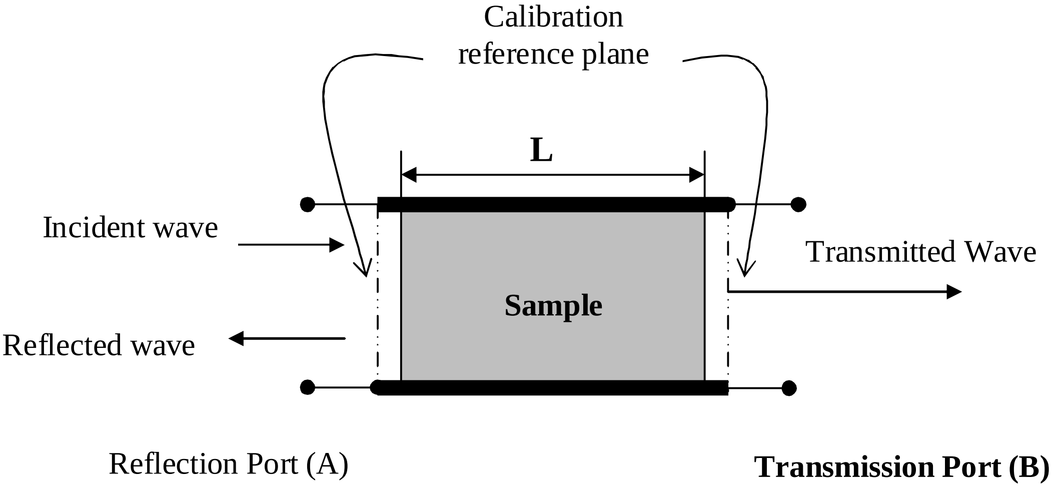

Figure (2). Two ports measurement .

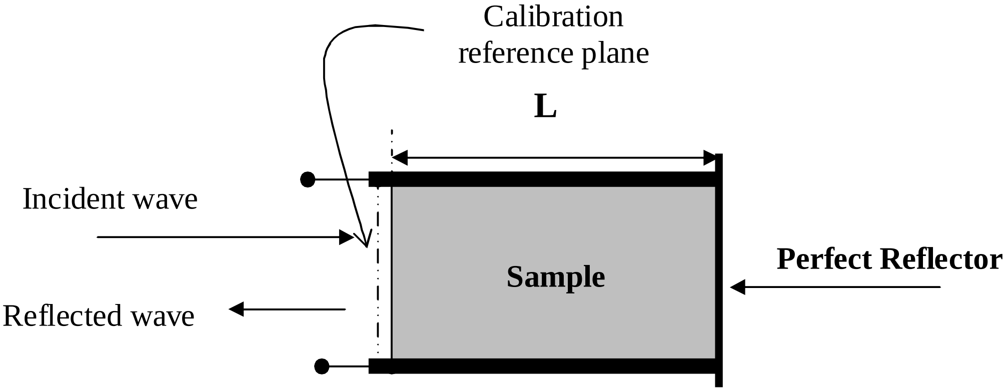

Figure (3). One port measurement .

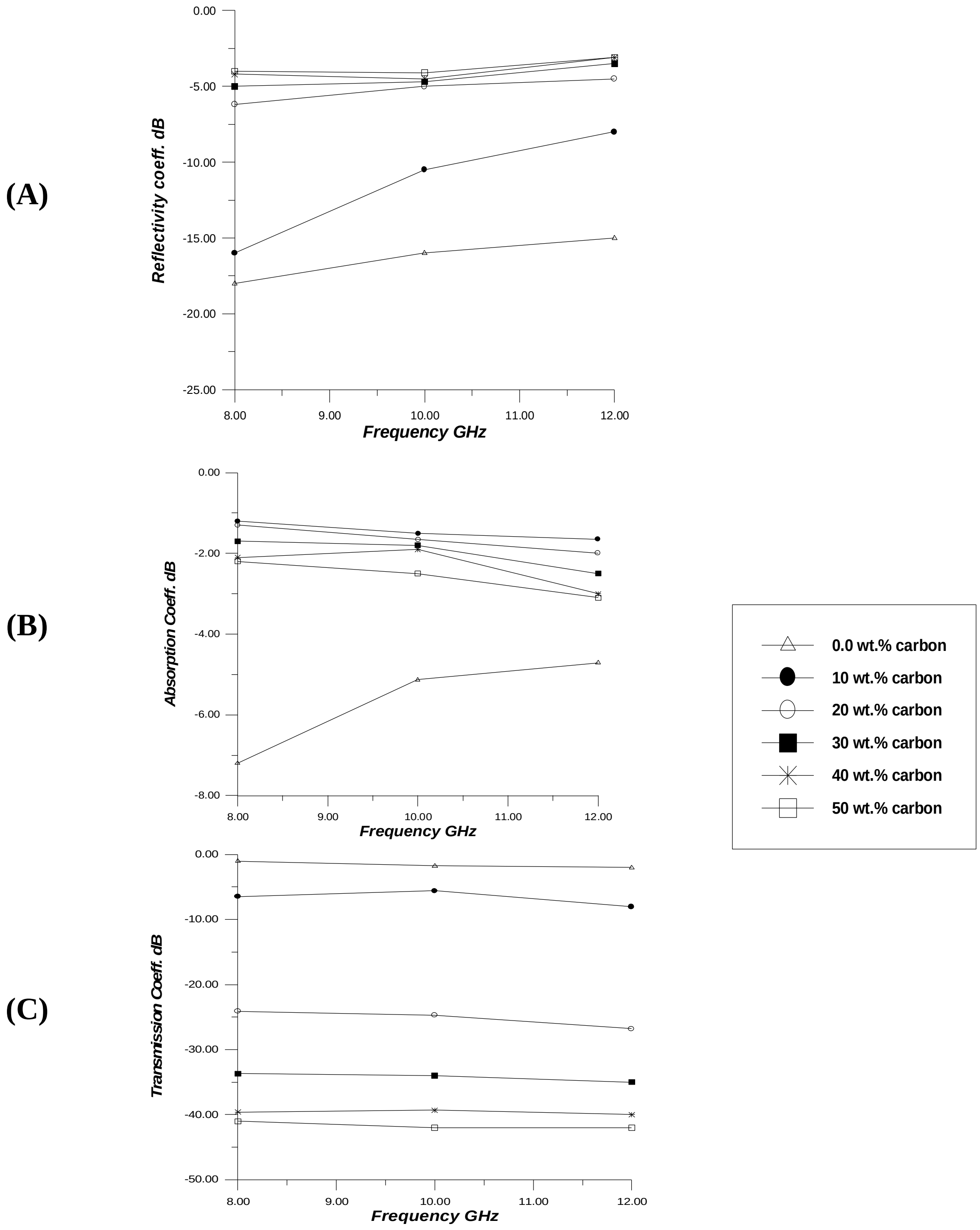

Figure (4). Frequency response for different weight percent of carbon black .

(A) Reflection coefficient ,(B) Transmission coefficient and (C) Absorption coefficient.

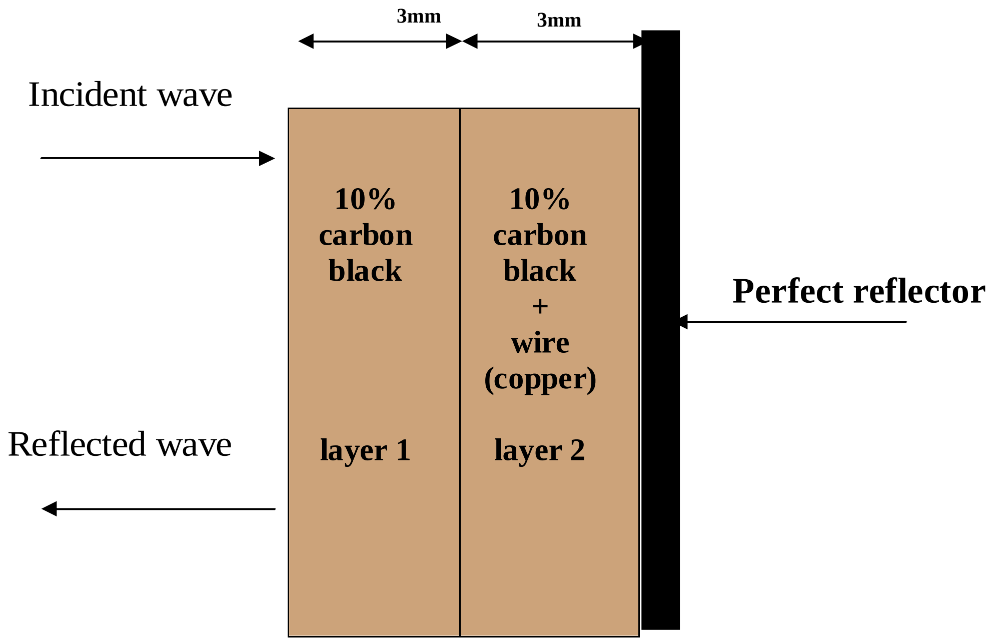

Figure (5). A catalyzed two-layer composite barrier .

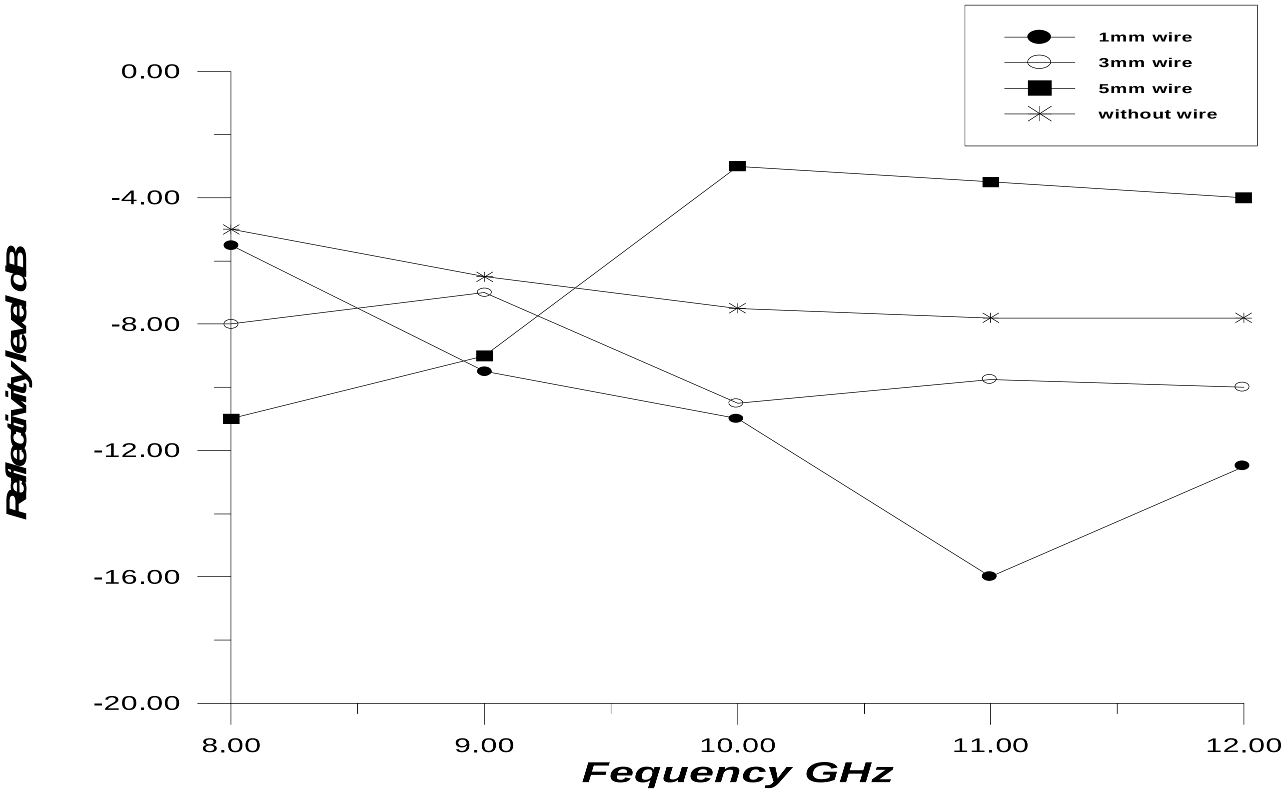

Figure (6). Relationship between wire length and frequency .

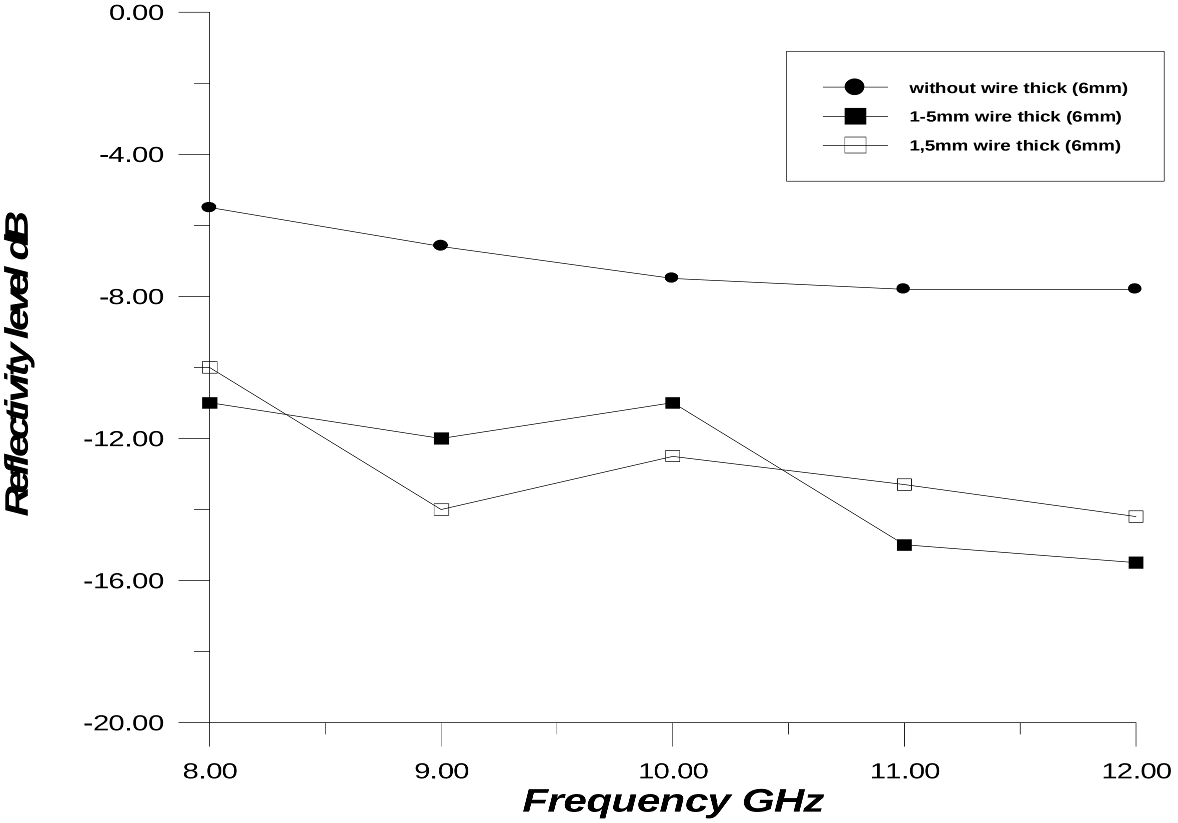

Figure (7). Comparison between single barrier(10% C) and catalyst barriers .

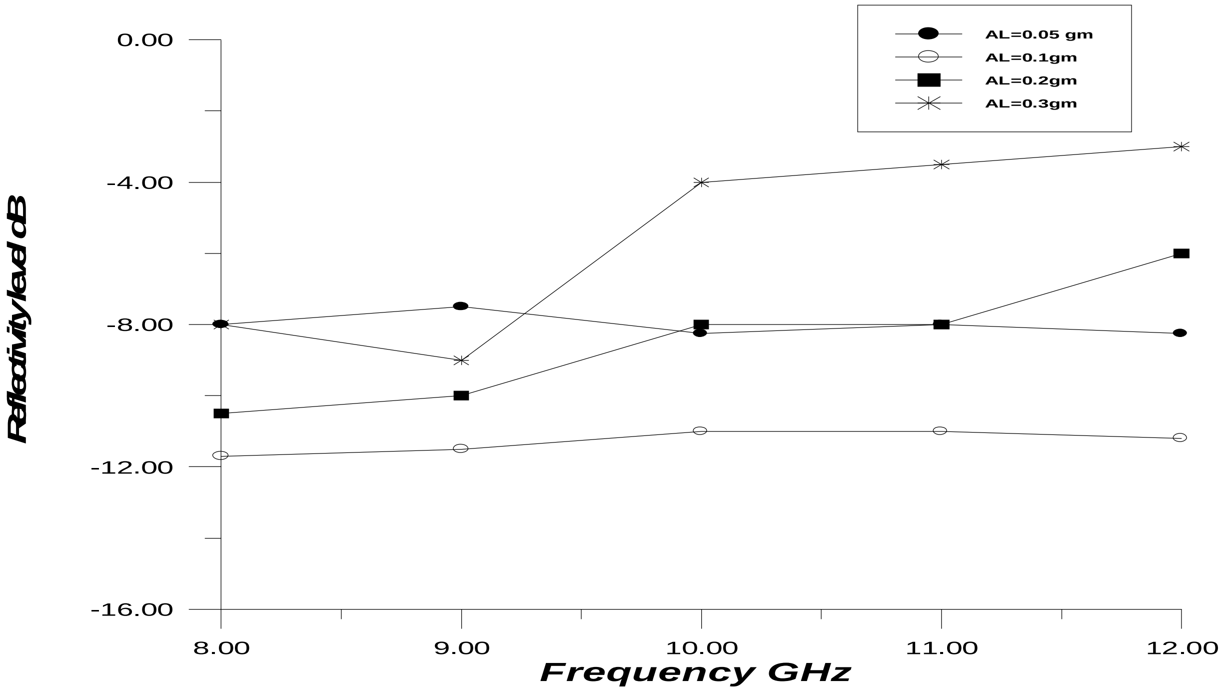

Figure (8). Reflectivity level of catalyst barrier versus frequency for different AL weight .