# The Research of Methods Based on Traveling Wave Suppression

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**Abstract**— The theory of traveling-wave scattering and two kinds of methods for restraining the traveling-wave scattering are represented in the paper. The traveling-wave scattering could be declined by shaping and radar absorbing material (RAM). The experimental results prove that inhibition effect of traveling-wave scattering using the above methods is prominent. A traveling-wave current comes into being, when a long, thin body is illuminated by grazing incident electromagnetic wave. The flowing traveling-wave current is reflected when it encounters the end of the truncation, and the traveling-wave scattering contributes a lot to the radar cross section (RCS) of the target. The traveling-wave scattering can be researched by making use of the existed concepts of antenna theory. In this paper, a sample of traveling-wave broad was manufactured. Firstly, we restrained the traveling-wave scattering by shaping. The end edge of traveling-wave broad was transformed into saw-tooth or circular arc shape, and measured results proved the shaping method could reduce the RCS of the traveling-wave broad by 10 dB at X-band. Moreover, we restrained the traveling-wave scattering by coating radar absorbing material on the surface of the broad. And the measured results showed that the method of radar absorbing material could reduce the RCS of the traveling-wave broad by more than 10 dB at X-band.

## 1. INTRODUCTION

Reducing target RCS by depressing strong scattering centers, i.e., air inlet, radar cabin, cockpit, etc., is the most primary approach to target stealth. Secondly, taking measures to prevent sub scattering centers caused by edge and surface travelling wave also plays important roles in RCS reduction. There exist a large number of components and parts with edges in target, which would result in strong radial diffraction in a wide angle, therefore, RCS contributed by target edges have great impact on target radar signature. Moreover, after strong scattering sources are suppressed, scattering from surface travelling wave would dominate the target signature, which is more difficult to reduce for stealth.

Travelling wave is a kind of surface current propagating along the direction of target length, the distinctive feature of which is to continuously radiate electromagnetic wave to the space during propagation. The source that emits travelling wave current can be RF generator and incident electromagnetic wave, and the latter leads to the travelling wave scattering.

## 2. PRINCIPLE OF TRAVELLING WAVE SCATTERING

Suppose an elongated conductor is excited by plane wave at a small angle. When the incident electric field has an axial component in the incident plane, the surface current induced by this component would flow along the axis, so the travelling wave current is produced. On the one hand, the travelling wave current will generate forward scattering similar to the radiation of travelling wave antenna, which would contribute to the bi-static scattering. On the other hand, if the elongated conductor is truncated at the terminal without load matching, the forward travelling wave would generate inverted secondary radiation due to the mismatch reflection once reaching the terminal. Consequently, the travelling wave contributes to the mono-static scattering as well. As for the travelling wave scattering, the illuminated target receives energy and guides it to transfer on the surface till the terminal, like the combination of antenna and transmission line, and then the energy will be reflected and reversely transform because of the load mismatch. The energy continually re-radiates during this process, which generates the so-called travelling wave scattering.

Generating traveling wave scattering must have two conditions: firstthe target is thin and long conductor, such as wire, cylinder, olive, strip plate, etc.; Second, the incident wave must have electric field component in the direction of propagation. For example, when the incident wave is vertical polarization, the wing and tail on target or missiles could generate strong wave traveling scattering. Using the radiation theory of traveling wave antenna can be well understood the travelling wave scattering. End-fire traveling wave antenna is used to analog traveling wave scattering by Peters et al., and the position of wave scattering peak of the long and thin conductor is well estimated by this means, but it has certain difficulty when estimating the value of traveling wave scattering, in general, the greater the conductivity, slenderness ratio and distal reflectivity of the object, the bigger the wave scattering.

## 3. STANDARD MODEL

In this paper, we choose a long flat plate as the standard model for study. In Fig. 1, the plate (length = 500 mm, width = 50 mm, thickness = 2 mm) is laid up vertically, and the incident direction varied in different azimuth angles. According to traveling-wave scattering theory, the traveling -wave scattering is strong when incident wave is parallel polarization, and the traveling-wave scattering is weak when incident wave is vertical polarization. So we could research the parallel polarization only.

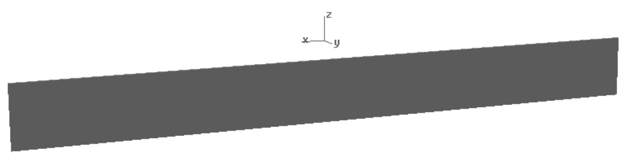

Figure 1: The long flat plate.

MOM [4,5] is used to calculate the RCS of the long flat plate because of its high accuracy [6]. In this paper, the calculate parameters are: $f = 10\,\text{GHz}$; Polarization: $HH$; Azimuth angle: $-180^\circ \sim 180^\circ$; Angle of pitch: $0^\circ$; Roll angle: $0^\circ$.

There are two ways of travelling wave suppression: one is by modifying the profile, the traveling wave electric current can generate the forward scattering as far as possible. The other is that the current traveling wave can be attenuated by adopting high performance absorbing materials. This article focuses on using shape method to suppress the traveling wave scattering.

There are two kinds of effective shape methods for suppression: First, the serrated modification in the tail; Second, the arc transition in the tail. Both methods can effectively restrain the traveling wave; the following are detailed analysis by taking the typical strip plate sample for example.

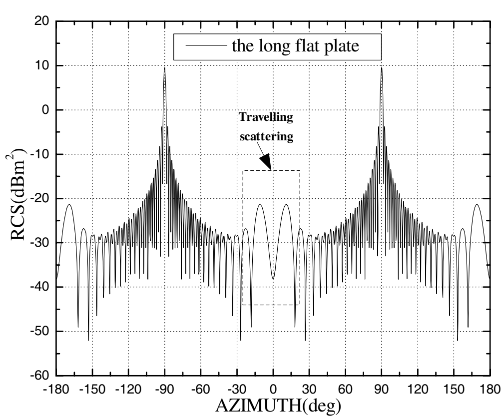


Figure 2: The scattering property of the long flat plate.

In Fig. 2, there are two high pioneers in the extent ($-20^\circ \sim 20^\circ$). The pioneer position is about $\pm 12^\circ$, and the amplitude is $-21\,\text{dBm}^2$. This is a typical travelling-scattering contribution, and this kind of contribution must be repressed in the RCS reduction of target.

## 4. REPRESSING METHODS

### 4.1. Saw-Tooth Shape

According to the above analyze, the vertical edge at the end bring a powerful traveling-wave scattering. One improved measure is changing the straight edge into saw-tooth edge. From Fig. 3 to Fig. 5, one saw-tooth project is adopted, whose saw-tooth angle is $160^\circ$, $140^\circ$, $120^\circ$.

All of above models are simulated by MOM with the same emulational parameter as before, the result of simulation is shown in Fig. 6.

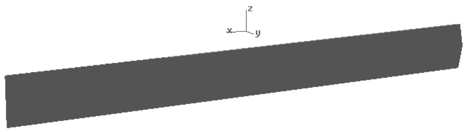

Figure 3: Long flat plate with angle 160°.

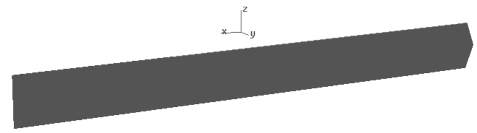

Figure 4: Long flat plate with angle 140°.

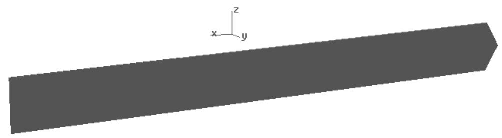

Figure 5: Long flat plate with a saw-tooth angle of 120°.

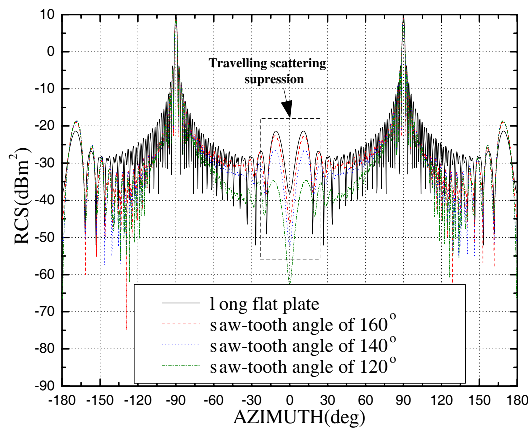


Figure 6: The scattering property of the long flat plate with saw-tooth shape (obtuse angle).

In Fig. 6, the traveling-wave scattering of the traveling-wave scattering vary evidently when the end of the long plate was transformed into saw-tooth shape. The average value of all of the four models within azimuth angle range of ±20° at head direction is shown in Table 1.

Table 1: The average value at the azimuth angle range of 0±20° (dBm$^2$).

| Long flat plate with vertical edge | Long flat plate with a saw-tooth angle of 160° | Long flat plate with a saw-tooth angle of 140° | Long flat plate with a saw-tooth angle of 120° |
|---|---|---|---|
| −25.74 | −27.01 | −30.69 | −38.39 |

In Table 1, the traveling-wave scattering trail off gradually with the saw-tooth edge minishing. The average value of traveling-wave scattering for the long flat plate with a saw-tooth angle of 120° is $-38.39\,\mathrm{dBm}^2$, which has more 12.65 dB attenuation than long flat plate with vertical edge. It is obvious that the traveling-wave scattering could be declined availably by transforming the edge into saw-tooth shape.

### 4.2. ARC Shape

According to the above analyze, the vertical edge at the end bring a powerful traveling-wave scattering, since he vertical edge can arose truncation effect. To trail off the truncation effect, the vertical edge at the end of the long flat plate should be transformed into circular arc shape. In Fig. 7 and Fig. 8, the circular arc radius is $\lambda/10(3\,\mathrm{mm})$ and $\lambda/4(7.5\,\mathrm{mm})$, respectively.

The two models are simulated by MOM with the same emulational parameter before, the result of simulation is shown in Fig. 9.

In Fig. 9, the traveling-wave scattering of the traveling-wave scattering weaken when the end of the long plate was transformed into arc shape. The average value of the two models within azimuth angle range of ±20° at head direction is shown in Table 2.

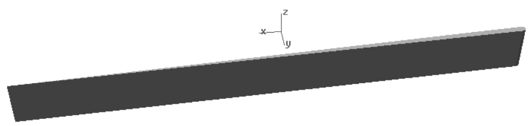

Figure 7: Long plat plate with a 3mm circular arc radius at the end.

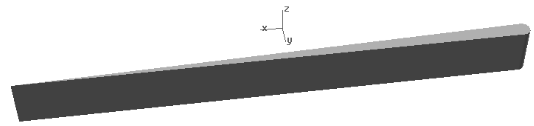

Figure 8: Long plat plate with a 3 mm circular arc radius at the end.

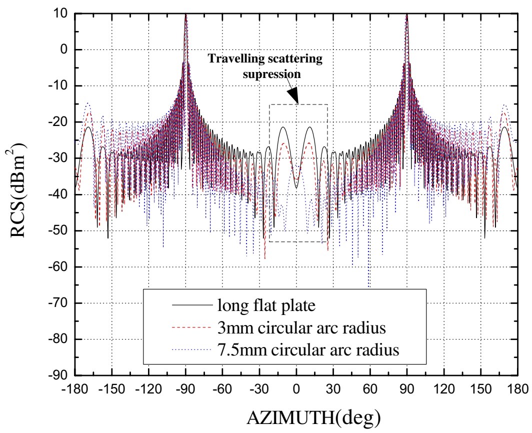


Figure 9: The scattering property of the long flat plate with circular arc radius at the end.

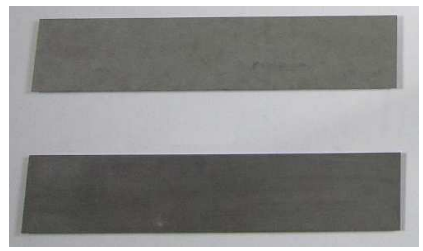

Figure 10: Long flat plate covering with radar absorbing material.

Table 2: The average value at the azimuth angle range of 0±20° (dBm$^2$).

| Long flat plate with vertical edge | Long plat plate with a 3 mm circular arc radius | Long plat plate with a 7.5 mm circular arc radius |
|---|---|---|
| −25.74 | −29.82 | −36.80 |

In Table 2, the traveling-wave scattering trail off gradually with the circular arc radius increasing. The average value of traveling-wave scattering for the long flat plate with a 3 mm circular arc radius is −36.80 dBm$^2$, which has more 11.06 dB attenuation than long flat plate with vertical edge.

### 4.3. Radar Absorbing Coat

It is a common method for target stealth that coating radar absorbing material on the surface of the broad to restraine the traveling-wave scattering. According to the above analyze, because of long flat plate bring obvious traveling-wave scattering peak, it is a ideal model to checkout the effect of traveling-wave restraint. So we manufacture some templets, and select two kind radar absorbing materials which is coated on the templets(only for one side of templets). As shown in Fig. 10.

The RCS test standard is GJB 5022-2001document. To get the result of traveling-wave restraint of the templets covering with RAM, a metallic flat plate is also be tested for RCS at the same frequency. The test curve and data is shown in the following figure.

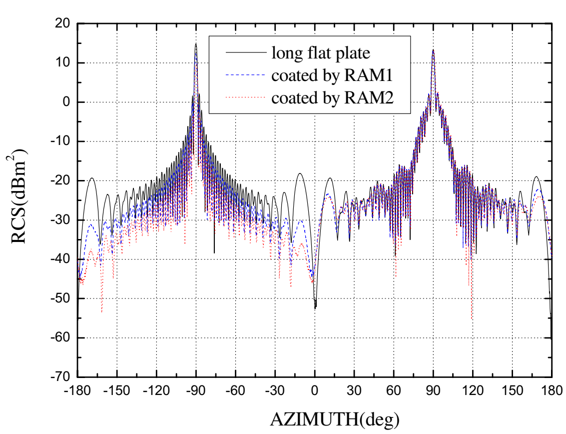

Table 3: The average value at the azimuth angle range between 0 and $-20°$ ($dBm^2$).

| Long flat plate | circular arc radius is 15 mm | circular arc radius is 30 mm |
|---|---|---|
| −25.74 | −41.43 | −44.07 |

In Table 3, when the circular arc radius go on increasing, the traveling-wave scattering become more and more weak. The average value of traveling-wave scattering for the long flat plate with a 30 mm circular arc radius is $-44.07\,dBm^2$, which has more 18.33 dB attenuation than long flat plate with vertical edge. Therefore, the traveling-wave scattering could be declined availably by transforming the edge into circular arc shape.

## 5. RESULT

After reducing the RCS of powerfull scattering source with effective measure in the design of high stealth target, traveling-wave scattering has became the chief threat in stealth design. Although traveling-wave scattering is a kind of low scattering, it can not be neglected, and must be restrained with effective measures. In this paper, traveling-wave scattering is restrained availably by using two kinds of methods in changing shape. Study on the representative model of long flat plate only be presented in the paper, but this method could be applied in the design of RCS reducing for some other complex object, and it has significant practical application value.

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