Aircraft Enhancement

The following notes represent a personal view of the mechanism of Aircraft Enhancement by Guy VK2KU.

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Aircraft Scatter
Part 1 – The Distance Factors

by Guy Fletcher VK2KU

Introduction

The scattering of radio signals by aircraft is an example of Bistatic Radar theory. This may sound like a difficult subject to understand, but the underlying principles are simple enough.
"Bistatic" just means that the receiver and the transmitter are in different places.

I am not going to write down the relevant equation for received signal strength, but let me walk you through the basic ideas –

- Imagine a transmitter of known power with an antenna of known gain – including any ground gain.
- Now imagine an aircraft some large distance away (say 300km), which presents some area which intercepts part of the radio signal.
- Calculate how much of the transmitted power falls on this "aircraft area". This is quite easy if you know the area, or can make some estimate of it.
- Assume that all (or most) of this power is reradiated by the aircraft area, acting much like a large antenna or dish with some radiation pattern.
- Having regard to the pattern of the scattered radiation, calculate how much power falls on the capture area of the receiving antenna (directly related to its gain and the wavelength).

The **only** part of this which presents any difficulty at all is the pattern of the radiation scattered by the aircraft, represented mathematically by what is called its "Scattering Factor".
The Scattering Factor depends very critically on the exact details of the aircraft's shape and orientation, and on the directions of the incoming and outgoing radiation; it includes the "aircraft area" mentioned above.
All the argument is about the nature of the Scattering Factor, and I will talk about my view of this in Part 2 of these notes.

You also need to include an estimate of atmospheric refraction (and of course the earth's curvature) in working out the directions of the incoming and outgoing radiation. This might be done by treating the earth as bigger than it actually is, using the 4/3 model.

It is an absolutely fundamental requirement that the aircraft be visible to both stations, having due regard to atmospheric refraction which normally increases the distance to the radio horizon. In most cases the portion of the aircraft path over which signals may be enhanced is dominated by this requirement. For paths where the aircraft lies off the direct line between transmitter and receiver, the scattering factor will determine how far off line enhancement is possible.

The Distance Factors

In Part 1, I will deal with the effect of distance from transmitter to aircraft (x) and from aircraft to receiver (y).
The power density (power per square metre) of any transmitted wave falls off with distance as the square of the distance. This is not a “loss” but rather a dilution of the signal as it is spread over an ever greater area as the distance increases.
So both x^2 and y^2 appear in the bottom line of the Bistatic Radar equation.
If both x and y are doubled, the bottom line increases by a factor of 16, and the received signal decreases by the same factor.
But the Scattering Factor will change too because of the different geometry!
Let’s stay focussed on just the distance factors x^2 and y^2.

Suppose that the aircraft is in midpath with x = y = 300km, and is flying directly along the line between transmitter and receiver.
I am going to work in 100s of km, to keep the arithmetic simple. You would have to use metres in the radar equation if you want to calculate actual signal strength.
Then the Distance Factors will be 3^2 and 3^2, making 81 in the bottom line.
Now suppose that the aircraft moves to a position with x = 200km and y = 400km.
The Distance Factors will now be 2^2 and 4^2, making 64 in the bottom line.
You can do this simple arithmetic for lots of positions and it will soon be obvious that 81 is the largest possible factor in the bottom line.
This means that the signal is **least** at midpath. This is the famous **dip** that people have mentioned.

Three important points about this simple sum:

- When you get close to either end of the path, x + y will be slightly greater than 600km, because of the elevation angle at the closer end. So the distance factor can never get down to zero, which would seem to give an infinite signal strength.
- When you put in reasonable figures for the amount of the path over which the aircraft is likely to be visible to both stations, the maximum signal enhancement at the “ends” compared with the middle is not much more than **half** an S-point. This is **not** a big effect, and too much is made of it.
- The change in the two directions from the aircraft to transmitter and receiver as the aircraft moves away from midpath will affect the Scattering Factor, and the change in Signal Strength from this will far outway any small effect in the distance factors.

Aircraft Scatter
Part 2 - The Scattering Factor

by Guy Fletcher VK2KU

Introduction

Scattering factors can be found in several ways:

- Look for them in some book or published paper
- Calculate them, usually by numerical methods on a computer
- Measure them directly, often using a smaller scale model of the object with the wavelength of the radiation scaled down by the same factor
- Analysis of simpler objects which have something in common with the desired object (the aircraft).

Detailed Scattering Factors for aircraft are not, as far as I know, publicly available in books or papers, though doubtless data does exist for most military aircraft.
Calculation is not, in principle, very difficult with the power of the modern computers on most of our desks, probably no more complicated than antenna analysis. But you need to have appropriate software, or the expertise to write your own.
Direct measurement of scaled models requires a serious facility with completely absorbing walls, again the domain of professionals and the military.
The analysis of simpler, but related, objects is often the favoured approach of physicists; it does not necessary solve the real problem, but it does give us some insight into the likely properties of scattering from the real object.

I am not simply going to present my personal opinion of the form of scattering from aircraft. The scattering factor of a commercial aircraft is at least the subject of some controversy among interested radio amateurs. Rather I propose to look at the scattering from some simpler objects first. This will give us a feel for the broad principles of scattering, and how it varies with the size of the object and its orientation. Then we can think about what sort of pattern we might reasonably expect from a real aircraft.

1. Small Metal Sphere

By small, I mean that the diameter is no more than $\lambda/10$.
For most of these examples I am going to take the wavelength λ to be exactly 2m, corresponding to a frequency of 150MHz, so the sphere has a diameter no greater than 200mm. If it were made of plastic, the pattern would be much the same, so the material is not really an issue.

This problem was understood a long time ago.
Look at Figure 1.

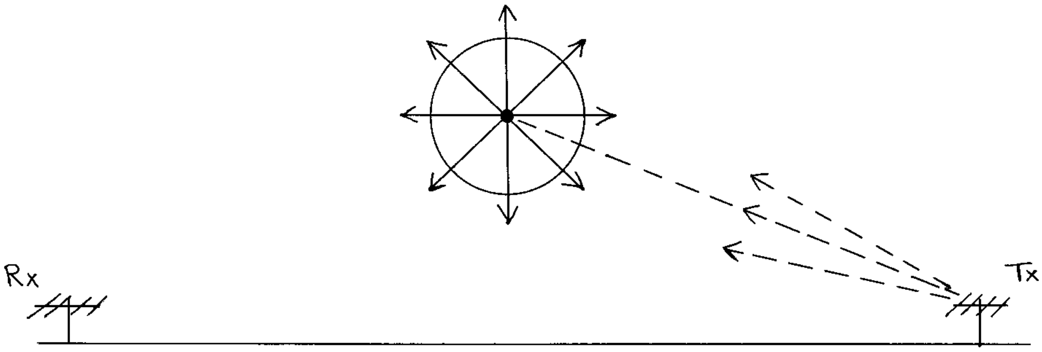

Fig. 1. Scattering from a Small Metal Sphere of diameter 200mm (λ/10).

The scattering is uniform in all directions, no lobes, just the same amount of radiation in every direction, though not very much because the sphere is small.
The reason for the uniformity is quite simple. The maximum difference in path that can occur is for radiation scattered backwards from the front and from the back of the sphere, and is no more than λ/5 (there and back again); this is small enough compared with λ that all the scattered radiation in any direction is in phase. The radiation does not cancel in any direction. In fact the scattering object need not even be spherical; the same argument works for an object of any shape provided that it is much smaller than λ.

This situation is actually quite familiar to us, though you may not recognize it.
It applies to sunlight falling on air molecules (actually on electrons in those molecules), and is the reason why the daytime sky is everywhere blue rather than black. The blueness comes from the fact that the intensity of scattered blue light is much greater than that of red light.

It also applies to VHF radio waves falling on those same air molecules, giving rise to tropo-scatter. Because the scattered intensity is the same in all directions, scattering can take place through large angles. It may be weak, but there are an awful lot of air molecules to contribute to the total intensity. It needs high power and big antennas to use this propagation mode for long distances, but at short range over obstructed paths I believe that tropo-scatter is responsible for good signals from quite modest equipment.

2. Larger Metal Sphere

As the diameter of the sphere increases, the path differences for scattering from different parts of the sphere become comparable with λ/2, and cancellation occurs in some directions. Figure 2 is an example of this.

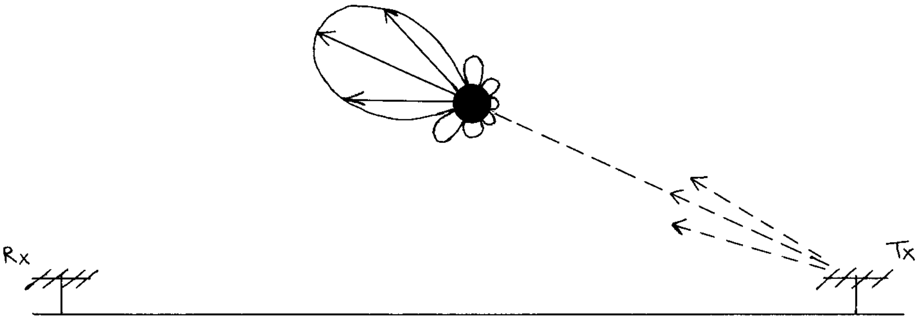

Fig. 2. Scattering from a Larger Metal Sphere

The scattered radiation breaks up into a strong forward lobe (for which all parts of the scattering object contribute in phase), and various weak backwards lobes and nulls where there is partial or complete cancellation.
It looks much like the pattern from a high-gain yagi, and this is no coincidence.

Atmospheric light scattering from particle pollution (like smog) falls into this category. The pollution looks far worse in directions close to the sun than away from it.

The scattering which falls within the forward lobe, right out to the first null, is called by engineers **Forward Scattering**. Everything else is called **Back Scattering**. It is important to understand this arbitrary definition, because it is not really intuitive. It would be more reasonable to call the scattering outside the forward lobe but still in a forward direction **Side Scattering**, but this is not the language used! Everything outside the main forward lobe is called **Back Scattering**, even if it is actually in a partially forward direction.

3. Large Flat Metal Plate, more or less square-on

Now let's consider a scattering object consisting of a very large square metal plate, more or less square-on to the transmitted radiation – see Figure 3.

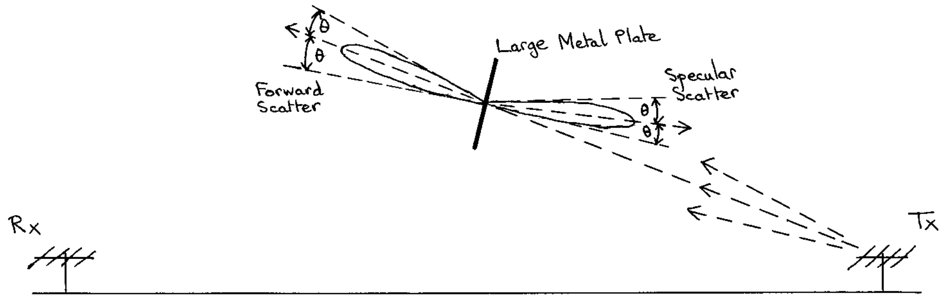

Fig. 3.

Scattering from a Large Metal Plate of side 1000m (500λ)

Each side of the plate is 1km (1000m), which is 500 λ at 150MHz. The metal is a good conductor, and most people would describe such a large flat reflecting plate as a mirror. All, or nearly all, the radiation which strikes the plate is reflected back towards the transmitter, just like an optical mirror. However the aperture of this reflected beam is limited by the size of the plate, and so diffraction broadening of the beam occurs; it spreads out slightly. It is easy to calculate the amount of spreading in terms of the angle θ between the central line of the beam and the first null point to either side. In this case for a wavelength of 2m, θ = 0.11°. The full width between the nulls on either side is of course 2 θ, and the full width between the 3dB points is very close to θ. The same amount of diffraction broadening occurs in both the vertical and horizontal planes because the plate is square.
Obviously this is **Back Scattering**, but unlike the previous case in Figure 2, there is one very strong major lobe within the backscattering, because the special shape of the mirror allows one direction in which all the scattered radiation is in phase.

The plate also puts a hole in the wavefront propagating past the plate along the original direction. The radiation just outside the plate edges diffracts slightly inwards behind the plate, and at a large distance behind the plate the effect of this is to create an identical slightly-broadened lobe in the forward direction, centred exactly along the line from the transmitter through the centre of the plate. This may seem strange at first, and I don't really want to digress now on the detailed reasons for this, but it is so. This is the
Forward Scattering from the plate.

It is worth pausing for a moment to think about the source of energy for the radiation in each of the 2 lobes.

The energy in the **Back Scattering** clearly comes from the radiation which strikes the plate and is reflected.

The energy in the **Forward Scattering** comes from the radiation which just misses the plate. If the plate was made from some totally absorbing material, there would be no **Back Scattering** at all, but the **Forward Scattering** would be exactly the same.

4. Smaller Flat Metal Plate, more or less square-on

Now suppose we use a smaller square metal plate than above, with side 64m, which just happens to be the approximate wingspan of a Boeing 747-400 aircraft. What difference will the smaller size make?

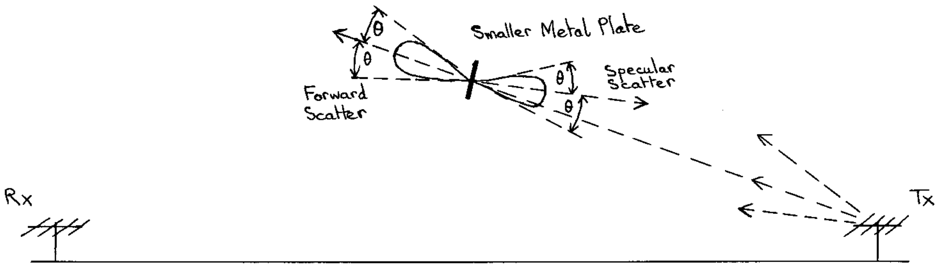

Fig. 4. Scattering from a Smaller Metal Plate of side 64m (32λ)

Qualitatively things will be much the same as before, but the energy in the 2 major lobes will obviously be less, and the diffraction broadening will be greater. In fact the angle θ will be 1.8° for a wavelength of 2m – see Figure 4.

The plate now has a side of only 32 λ at a wavelength of 2m, and this is a bit small to be called a mirror.

So instead of talking about **reflection** in the backwards direction, I will call it **specular scatter**, because the diffraction broadening is now a major feature, but the direction of this lobe still peaks in the direction of mirror-like (or specular) behaviour.

5. Small Flat Metal Plate, horizontal

Our final example is to turn the small plate of the previous example horizontal.
Seen from the transmitter it will have the same width, but its apparent height will be reduced by a factor which depends on the vertical angle at which the transmitted radiation falls on the plate – see Figure 5.

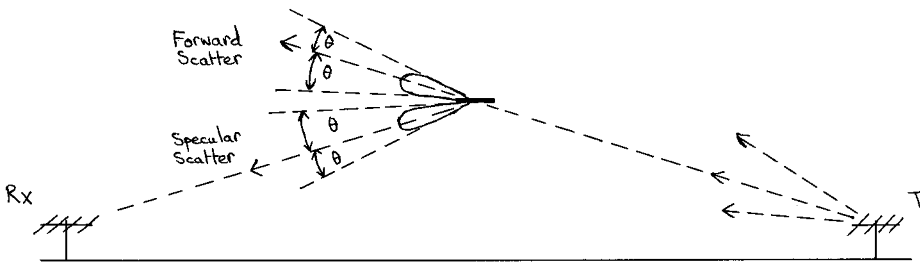

Fig. 5. Scattering from a Horizontal Small Metal Plate at 1296MHz

I don’t want to quibble over numbers; by all means change mine if you like!
But I have chosen a height above ground for the plate of 10km (32 808 ft).
With the usual allowance for atmospheric refraction, it turns out that the radiation approaches the plate from below at an angle of 3 to 4 degrees over a surprisingly wide range of transmitter distances. You would expect the angle to get smaller as the transmitter distance increases, but the curve of the earth takes out most of this change!
I am going to use an angle of 4° in my example.
For this value the apparent height of the plate is reduced from 64m to 4.5m, which increases the vertical diffraction angle θ from 1.8° to 27° at a wavelength of 2m, but from 0.2° to only 3° at a wavelength of 23cm (1296MHz).

It is clear that the **Forward Scattering** lobe is now broad enough to come back down to the receiver on the ground, overlapping with the **Specular Scattering** lobe, at least at a wavelength of 2m. However at a wavelength of 23cm, the **Forward Scattering** lobe will not quite make it back to the ground. I don’t think it is possible to have the **Specular Scattering** lobe extending above horizontal, but this is not an issue anyway since this lobe will always make it back to the ground anyway.

Suppose we were somehow to attach such a plate to the underside of a 747-400! At a wavelength of 2m we might expect excellent aircraft scatter near midpath. However at a wavelength of 23cm we would expect a contribution from the **Specular** lobe, but none from the **Forward Scattering**.

6. Real Aircraft

Obviously a real aircraft, even a 747, is not like a flat square metal plate of side 64m, but it surely has at least something in common with this. It presents somewhat less area to the transmitted radiation, and it certainly has less horizontal surface area.

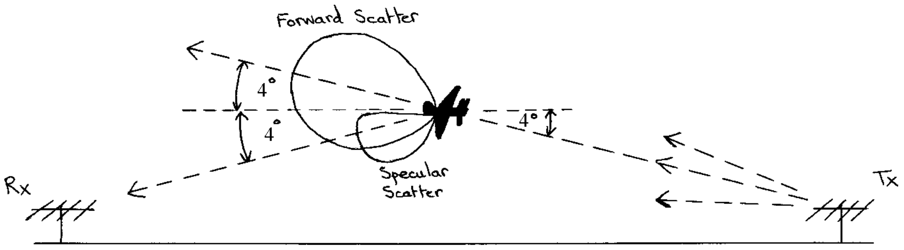

Fig. 6. Possible Scattering from a real Aircraft at 1296MHz

So the strength of the **Specular Scattering** lobe will be less, and the vertical (and horizontal) diffraction broadening of the **Forward Scattering** lobe will be greater, helping to bring this back down to the receiver on the earth's surface.

Some amateurs who have studied aircraft enhancement do not believe in the existence of the **Specular Scattering** lobe at all, and at a wavelength of 2m this scarcely matters.
However at 23cm I think that this contribution may be important; aircraft scatter at 23cm is most certainly observed.

I have deliberately refrained from putting in numbers to estimate the actual signal strength, because of the uncertainty in the width of the diffraction lobes. At 2m it might be reasonable to take simply the strength at the lobe centre, and Gordon VK2ZAB did this in his original calculations, though there is still a large uncertainty about the effective scattering area (which comes into the radar equation squared).

7. Conclusions

We can draw a number of conclusions from this analysis:

1. The aircraft must be visible to both stations.
2. The Forward Scattering lobe will be lost into space unless the antennas are directed at the lowest angle possible, and this limits enhancement to the central part of the aircraft path.
3. The Specular Scattering lobe is directed downwards at the same angle as the incident radiation was directed upwards, again limiting us to the central part of the aircraft path.
4. Obviously where one station has a very poor horizon, he can do no better than point at that horizon. There is little future in beaming straight upwards.
5. The footprint of the scattered radiation on the ground is a long thin sausage, much like the effect of shining a torch onto the ground at a very shallow angle, but even narrower because the diffraction is narrower in a transverse direction.
6. If you are lucky enough to have aircraft flying directly along the line between stations, then the duration of the enhancement window will be similar on all bands.
7. But if the aircraft is crossing the direct line between stations at an angle, then the sausage will move sideways and this determines the duration of the window, which is then 9 times shorter on 23cm than on 2m.

Earlier references on this topic include:

1. "Aircraft Enhancement of VHF/UHF Signals"
by Doug McArthur VK3UM, AR July 1985, pp4-6.

2. "Enhanced VHF/UHF Signal Levels due to Aircraft"
by Gordon McDonald VK2ZAB, AR October 1985, pp8-9.

3. "Aircraft Enhancement of VHF/UHF Signals - towards a propagation model"
by Roger Harrison VK2ZTB (now VK2ZRH),AR November 1985, pp9-13.

4. "Propagation via Reflections from Aircraft"
by Gordon McDonald VK2ZAB, AR Feb 1986, pp4-7.

5. "Aircraft Enhancement - another view"
by Ian Cowan VK1BG, AR March 1989, pp18-20.

6. "Signals Reflected via Aircraft"
by Gordon McDonald VK2ZAB, AR May 1989, pp10-11.

7. "More on Aircraft Enhancement"
by Ian Cowan VK1BG, AR July 1989, p61.

8. "Aircraft Enhancement – Some Insights from Bistatic Radar Theory"
by Rex Moncur VK7MO, GippsTech Proceedings 2000, p1-19.

9. "Predicting Aircraft Enhancement Opportunities"
by Chris Morley VK3KME, GippsTech Proceedings 2001, p35-44.