Aircraft Reflections at VHF
Can we use them for Communications?

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What do aircraft reflections sound like?

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- Most noticeable on fairly weak signals over fairly long paths (>50km).
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What causes the fluctuation in signal strength?

The received signal is the sum of the signals coming by the direct and reflected paths. Sometimes these signals will be in phase and add to give an enhanced signal. Sometimes they will be out of phase and tend to cancel each other, giving a weakened signal. The phase relationship at any time depends on the difference between the direct and reflected signal path lengths.
So........

For normal communication, aircraft reflections are just a nuisance – they cause fading which can be particularly bad when there's a lot of air traffic causing multiple aircraft echoes.

However, maybe we can use reflected signals when the direct signal is too weak.....
Over what range can aircraft reflections be heard?

- Assuming transmitter and receiver are at sea level with an unobstructed view of the horizon, the minimum height of an aircraft midway between them which would be mutually visible (radio-wise) can be calculated from:

\[ H = \left( \frac{D}{8.24} \right)^2 \]

Where:
- \( H \) is the aircraft height in metres
- \( D \) is the RX/TX distance in km

- So, for example, the maximum range for an aircraft at 8000m (26,000ft) is 740km,

- Note that the above formula assumes the standard refraction model for the atmosphere.
What signal strength can be expected from reflections?

- The received signal level can be estimated using the Bi-static radar equation.
- Assume the reflecting area is 100m² (the plan area of a modern passenger jet is between 200m² and 1,000m²).
- A 50w transmitter, with antenna gains of 10dB at each end of the link and a 3dB noise figure receiver should give a signal/noise ratio of about 6dB in a 10Hz bandwidth at 144MHz: - a weak but usable signal with a low data rate digital mode.
Looking at the reflected signal in more detail (1)

- Because the aircraft is moving, the length of the signal path is also changing.

- At a wavelength of 2m, if the path length is changing at a rate of 2 metres per second, the reflected signal will be received with a frequency offset of 1Hz from that transmitted.
Looking at the reflected signal in more detail (2)

- If the reflected path length is increasing, the frequency of the reflected signal will be lower than that transmitted. The opposite will occur when the path length is decreasing.

- There are two paths to be considered; from the transmitter to the aircraft and from the aircraft to the receiver. One of these may be increasing while the other is decreasing, so reducing or even cancelling the overall frequency shift.
The maths bit...

The total frequency shift ($\Delta f$) on the received signal can be calculated from:

$$\Delta f = \frac{(vt + vr) \times f}{1080} \text{ Hz}$$

where:

- $vt$ is the velocity of a/c towards TX (km/hr)
- $vr$ is the velocity of a/c towards RX (km/hr)
- $f$ is the transmitter frequency in Mhz

From the above, the max. frequency shift for a signal at 144MHz reflected by a distant aircraft travelling at 800km/hr directly towards the TX/RX line is 213Hz.
The story so far....

- Signals reflected off aircraft are generally shifted in frequency from the transmitted signal.
- The frequency shift will vary, depending on the position, direction and speed of the aircraft relative to the line between the transmitter and receiver.
- At 2m, the maximum frequency shift will be about +/-200Hz.
- We can expect to hear reflections from stations up to 600-700km away.

So, how can we detect these signals?
Requirements to observe reflections

- Very narrow filters required to get adequate sensitivity and to separate the reflected signal(s) from the direct signal.

- Good frequency stability required at both transmitter and receiver.

- Steady carrier wave signals without modulation are needed.

- The VHF beacon network is a good source of signals for testing.
Spectrum Analysis with the FFT

- The FFT (Fast Fourier Transform) provides a good means of filtering out the reflected signals.

- FFT programs which run on any modern PC are available for free download from the internet.

- Spectran (written by I2PHD and IK2CZL) has been used successfully and is available at http://www.weaksignals.com

- Input to the FFT program is from the audio output of a normal SSB receiver via the PC's sound card.
Schematic of FFT/Waterfall Display

Radio Receiver
(set to SSB or CW)

Audio

PC Sound Card

Audio samples at 11.025ks/s

PC

16,384 filters
0.34Hz spacing
0Hz to 5.57KHz

Amplitude demodulators

FFT Process (software)

PC Screen
The Equipment
General Observations

• The frequency offset from the direct signal depends on the rate at which the length of the transmission path is increasing/decreasing.

• Almost always, the reflection trace of an aircraft shows a decreasing frequency with time.

• A reflection trace running almost parallel to the direct signal trace is probably via an aircraft travelling along the receiver/transmitter line.
Signal Enhancement

Many reflected signals appear to peak quite strongly when the frequency offset is close to zero. This is usually the case when the aircraft is crossing the direct RX/TX path.

This effect is known as “Forward-Scatter Enhancement” and is discussed in some detail in a paper by Rex Moncur (VK7MO), which can be found at:

www.users.bigpond.com/anvdg/ENHANCEMENT%20PAPER%20final.doc

Rex predicts enhancements of up to 24dB on 2m.
Desirable features for a digital mode using aircraft reflections

- Capability to operate at weak signal levels
- Ability to cope with signals varying in frequency
- Not confused by multiple copies of the same signal on closely spaced frequencies
- Ability to cope with signals which may fade out for periods of time and achieve rapid synchronisation when they re-appear.
- Make use of multiple reflections (when present) to enhance reception.
What mode to use?

- Must operate a very low signal levels – This rules out most of the standard modes, e.g. RTTY, PSK31 etc.

- Multi-tone modes, such as MFSK16 & JT65 are confused by frequency shifted copies of the same signal.

- For test purposes, a simple mode using a slow version of Hellschreiber was chosen.
Hellschreiber Principles

- Characters are scanned bottom to top, left to right.
- In Feld-Hell, each pixel duration is 8.163ms, giving a character rate of 150 characters/sec.
- Basic Feld-Hell uses on/off carrier keying – carrier on = black.
Feld-Hell Principle of Operation

Basic Printing mechanism

Print-out, showing sloping text caused by speed difference between transmitter and receiver
Feld-Hell Machine
What does Feld-Hell sound like?

Like this....
Feld-Hell off-air (80m)
Slow-Feld

- For aircraft reflection tests, a very much slowed down version of Feld-Hell was used. This greatly reduces the bandwidth of the signal and allows narrow filtering to be used to detect the weak signals.

- Three speeds have been used:
  3 characters/min (400ms/pixel)
  6 characters/min (200ms/pixel)
  12 characters/min (100ms/pixel)

- G3PPT has developed a special program for use with aircraft reflections, called Slowfeldxpas which can be downloaded from:
  http://www.lsear.freeserve.co.uk/slowfeldxpas.zip
What does Slow-Feld sound like?

At 12 characters/min, like this....
Why choose Slow-Feld?

- It doesn't need bit or character synchronisation (i.e. as soon as there's a signal, it starts working).

- Being a simple on/off keyed mode, it is not confused by frequency shifted multiple copies of the same signal.

- It's a “fuzzy” mode. i.e. character recognition is done directly by eye, allowing errors and short fades to be overcome by human interpretation.

- Slow-Feld sensitivity is estimated to be about 10dB better than standard modes, such as PSK31.

- Easy to implement for test purposes.
Slowfeldxpas off-air(2m)

PA0OCD as received at G3LNM at 3 cpm
Slowfeldxpas off-air(2m)

G3SMW as received at G3LNM at 3 cpm
Slowfeldxpas off-air(2m)

PA0OCD as received at G3LNM at 12 cpm
G3LNM as received at PA0OCD by aircraft reflections at 3 chars/min
PA0OCD at G3LNM
G3SMW at G3LNM
Conclusions

- Aircraft reflections have been successfully used for communication although the data rate was slow and sometimes intermittent.

- Aircraft reflections can give a usable signal level when there is no direct path.

- The increasing level of air traffic makes it possible to have almost continuous communication via busy routes.
Conclusions (2)

- Work needs to be done to develop a modulation/data encoding mode that will operate with the peculiar characteristics of the reflected signal path.

- If possible, the transmission rate should adapt to the received signal level so that when the signal is strong, the data rate increases. This implies a two way system, which would also allow automatic repeat requests (ARQ) when characters are received in error.
Useful Websites

1. G3PPT website – links to details on aircraft reflection and Slowfeldxpas program download:
   http://www.lsear.freeserve.co.uk/reflections.pdf

2. Information on aircraft reflection work in Australia:
   http://www.geocities.com/wilgonis/doppler.htm

3. Paper on forward scatter enhancement by VK7MO:
   www.users.bigpond.com/anvdg/ENHANCEMENT%20PAPER%20final.doc

4. Spectran (FFT) download:
   http://www.weaksignals.com

5. NL19222 website, with links to a wide range of digital mode programs etc.:
   http://www.xs4all.nl/~nl9222/

6. Multipsk download by F6CTE – a good (free) digital mode program:
   http://members.aol.com/f6cte/MULTIPSK.ZIP