Installing an ATC Transponder on a Small Aircraft

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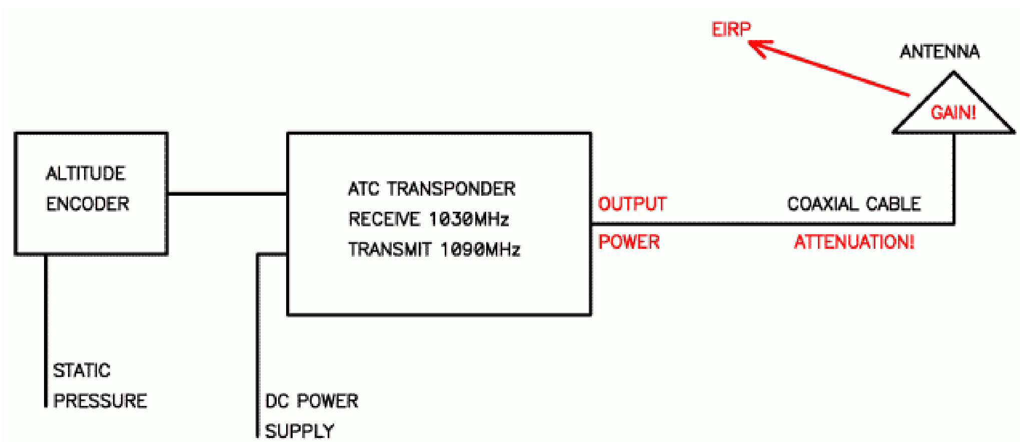
Aviation radars require powerful transmitters, large antennas and sensitive receivers, since the signal reflected from a small and distant target is very weak. The radar echo can be amplified several orders of magnitude with a device called transponder. Further, a radar transponder may add to its reply additional information, like the code assigned to the particular aircraft (mode-A), the pressure altitude (mode-C) or the information from other flight instruments as well (mode-S).

Aviation-radar transponders were invented during the second world war for a completely different purpose: as Identification Friend-or-Foe (IFF) transponders. After the war, the same military radar transponders were found very useful in civil aviation as well. At that time, information theory has not been invented yet and today the specifications of an ATC transponder may look very obsolete to a modern communications engineer!

A typical ATC transponder installation on-board an aircraft includes the transponder itself, an antenna, an altitude encoder and the corresponding wiring harness:



What is the required power of an ATC transponder? ICAO specifies the Effective Isotropic Radiated Power (EIRP), therefore considering the output power of the transponder itself, the inevitable power losses due to antenna-cable attenuation and an eventual antenna gain. The peak (pulsed) EIRP should be between 125W (+21dBW) and 500W (+27dBW). The lower EIRP limit is further reduced to 70W (+18.5dBW) for aircraft flying below FL150.

What is the practical difference between a 175W transponder and a 250W transponder? A good installation will result in about 2dB of cable loss (factor of about 1.6). The typical antenna gain is also around 2dBi (same factor of 1.6), so the EIRP will be very close to the actual transponder output power. Both 175W and 250W transponders fully meet all ICAO specifications. Therefore it makes sense to install the cheaper 175W model.

The more expensive 250W model is only needed in the case of a rather long cable with high losses. The 250W is not just more expensive, it also requires more DC power! The latter may be unimportant in powered aircraft. On the other hand, DC power is a precious resource in gliders and motorgliders during unpowered flight. A power-hungry transponder may discharge the battery, affecting other electrically-powered equipment and making the restart of the engine of a motorglider impossible.

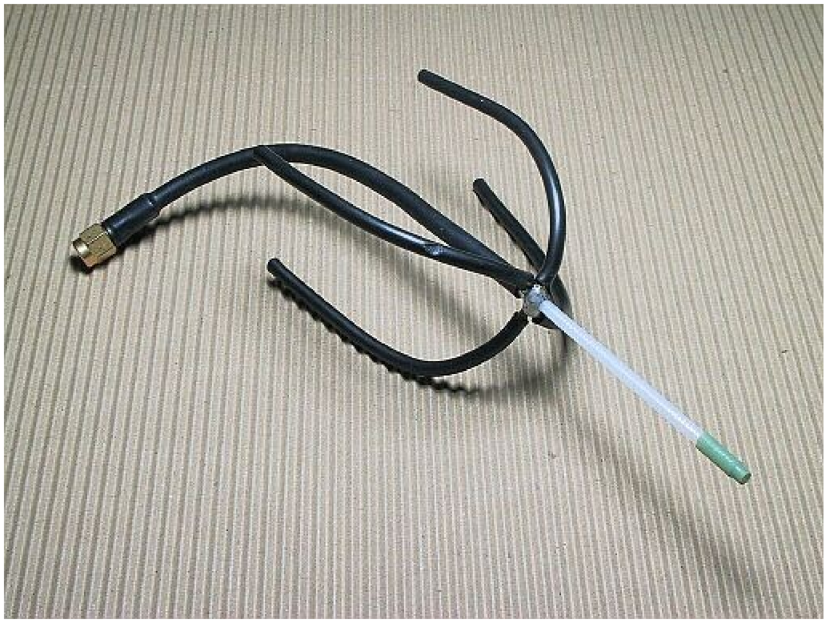
In spite of their relatively large peak output power, the average power consumption of ATC transponders is much lower. The duty cycle of the transmitter is usually well below 1%! Old vacuum-tube ATC transponders may have an average DC power drain between 15W and 30W. On the other hand, solid-state units may require just a few watts of average DC power. Last but not least, several watts of DC power may be required by some old pressure-altitude transducers to operate their internal heaters!

In the case of gliders or motorgliders, both the power drain of the transponder itself as well as the power drain of the altitude encoder have to be considered. Even in the case of powered aircraft, less power means less heat and less heat means less failures of all electronic devices! Old power-hungry vacuum-tube transponders, solid-state transponders with power-hungry, bright LED displays and old altitude encoders with internal heaters are all to be avoided!

While it is relatively easy to measure DC power drain or specify the peak (pulsed) transponder output power, details about the antenna installation are less obvious. The most popular ATC-transponder antenna is certainly the blade antenna:

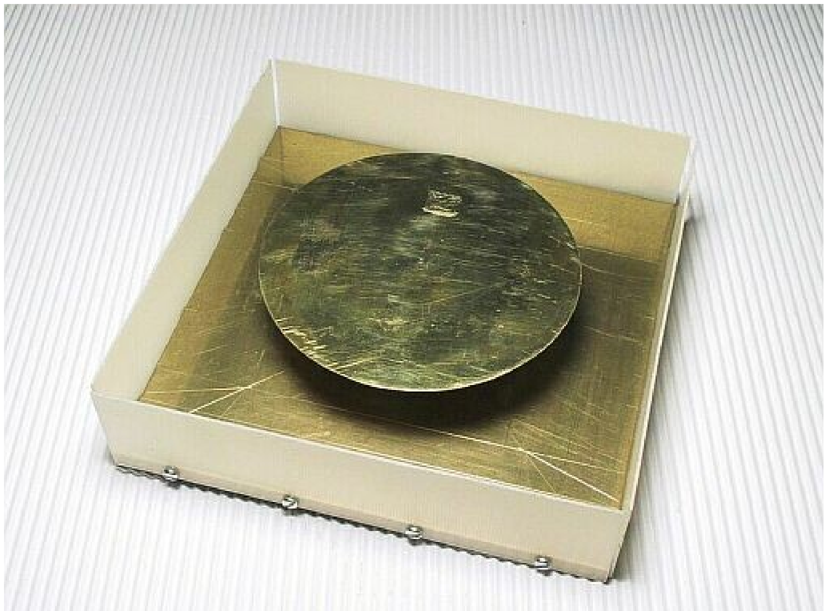
The antenna is shaped as a fin to reduce aerodynamic drag. A blade antenna has a gain of around 2dBi when installed correctly on a large metal ground plane. This antenna is therefore suitable for installation on metal fuselages. In the case of composite fuselages, the antenna requires an additional sheet of metal to act as a ground plane.

Since glassfiber fuselages are transparent to radio waves, it may be more convenient to install a simple antenna inside the aircraft. Such an antenna does not require any holes in the fuselage, it does not generate aerodynamic drag and can not be broken away while handling the aircraft. A very simple solution is a ground-plane antenna, made from readily available materials:



High-speed military aircraft require somewhat different antennas. To avoid aerodynamic drag, all antennas are made flat with the surface of the fuselage or wings. An annular-slot military IFF antenna is shown below:

Besides avoiding aerodynamic drag, the annular slot has yet another advantage: it provides between 4dB and 6dB antenna gain, much more than the simple blade or ground-plane antenna! I therefore makes sense to consider a similar antenna also for small civilian aircraft, provided that it can be made inexpensive and lightweight. A lightweight prototype antenna was therefore developed for installation inside glassfiber or other fuselages, that are transparent to radio waves:



Practical experiments using this antenna with both an ATC transponder and with a DME (same frequency band) gave excellent results. Thanks to its gain, this antenna can fully meet the ICAO specifications with a transponder output power of only 25W.

The antenna gain is not the only advantage of the new transponder antenna. Since the new antenna does not require cutting holes in the fuselage, it can be installed quickly. Since it is not constrained by aerodynamic drag or other requirements, it can be positioned both to keep the coaxial cable to the transponder as short as possible and to avoid the shading of the aircraft structure at the same time.

Shading of the aircraft structure may attenuate radio signals by a factor of more than 100 (20dB)! Poor ATC transponder performance can usually be attributed to an unfortunate antenna installation including both structural shading in some directions and excessive cable length resulting in additional signal loss. Bad quality components like computer-grade BNC connectors and cheap RG-58 (polyethilene dielectric) antenna cable make the problem even worse.

The only way to solve the shading problem on large commercial aircraft is to install special “diversity” or “dual” transponders, connected to two widely-spaced antennas. On the other hand, on small aircraft it makes sense to find the most suitable antenna and install it in the best place, using good-quality connectors and the shortest teflon-dielectric cable.