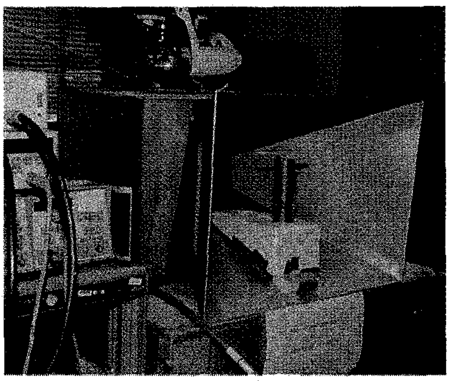
RPVs

Tiny, microwave powered, remotely piloted vehicles



Dale Kuska

As the name implies, a remotely piloted vehicle (RPV) has its motion controlled by an outside source. A commonly encountered example is a radio controlled model airplane. In this case, the pilot always has the aircraft and ground in view. It is a simple process (in principle) to fly and land. For vehicles that move out of the pilot's view, an onboard sensor is needed to determine motion and location relative to the terrain. Usually the sensor is a video camera, but radar and infrared systems also can be used.

RPVs have several big advantages over manned vehicles. The obvious one is that unmanned vehicles do not expose the pilots to dangerous situations. For this reason RPVs have always been of interest to the military. Another advantage is that RPVs do not require pilot support systems such as seating, controls, emergency escape mechanisms, oxygen supplies and pressurization. These systems can add a significant amount of weight and volume to a vehicle.

On the other hand, the sensor information from the vehicle must be of high quality and fidelity, and be available in real time. (That is, it cannot be delayed in time.) If for some reason the sensor fails or the data link to the pilot is interrupted, then the vehicle can be lost or destroyed.

David C. Jenn

Several countries currently have military RPVs in use. They range in size from a large missile to a small airplane. They are usually used to gather information on the battlefield. The US Department of Defense (DoD) currently has a research program to develop a miniature flying RPV with military and civilian applications.

Small RPVs have been dubbed micro RPVs (MRPVs), where the prefix micro refers to their small size. The first generation would be only a couple of inches in size. This MRPV could be carried by a person and able to fly inside buildings. A vehicle this small could be used to monitor dangerous environmental hazards such as a contaminated nuclear facility. It could also gather information in hostage situations. Subsequent generations of the vehicle could be made as small as the then current technology permits.

The design for such a small vehicle presents some unique engineering challenges. Several basic tradeoffs must be performed in the areas of aerodynamics, propulsion, energy sources, control and onboard sensors. Obviously as the vehicle's size is reduced, the weight and power consumption of the systems on board must also be reduced.

One way to reduce weight is to "beam" microwave energy to the vehicle. This energy is then converted to a dc signal which drives a motor. This approach is called wireless power transmission (WPT). It was first demonstrated as long ago as 1964. Since WPT eliminates the need for a battery on board, the potential volume and weight savings are significant.

Miniature rotorcraft configuration

An example of a miniature microwave powered rotorcraft is illustrated in Fig 1. A block diagram of the on board systems is shown in Fig. 2. The RPV body is cylindrical and covered with conducting film. The body is slotted and the top and bottom halves are connected to the receive transmission line. Therefore, the RPV body resembles a fat dipole with the radiation pattern shown. The broad pattern allows the RPV to pitch and roll without a significant loss in the receive antenna gain. A small battery is included to power the onboard systems during short term power dropouts.

A diode circuit is used to rectify the received sinusoidal continuous wave (cw) signal of frequency f_0. Since diodes are nonlinear devices, harmonics of the frequency f_0 are generated as a byproduct of the rectification process. The second harmonic, $2f_0$, is used as a carrier for transmitting telemetry and image data back to the ground station. The advantage of using the second harmonic is that clutter that arises from reflections and scattering of the power beaming will not interfere with the telemetry signal because they are at different frequencies.

Aerodynamic stability of a rotorcraft with a single rotor requires a vertical stabilizer. Helicopters commonly employ a boom with a tail rotor. This would destroy the rotational symmetry of the RPV body, and degrade the antenna pattern symmetry as well.

A tail boom can be avoided by using two counter-rotating main rotors. Stability and flight control are achieved using slipstream paddles that are made of so-called "smart materials." There are no mechanical parts in

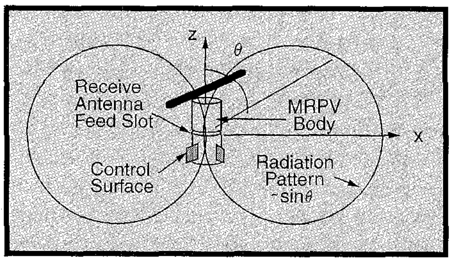


Fig. 1 MRPV polar pattern cut

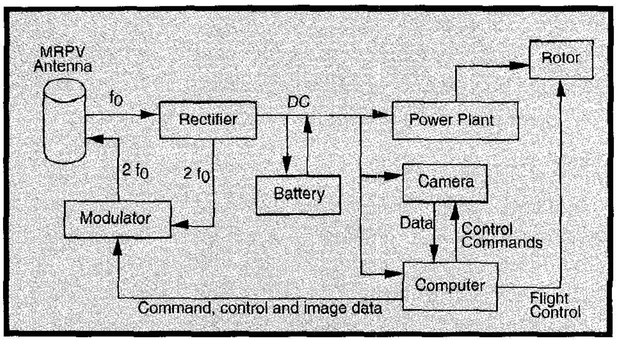


Fig. 2 Block diagram of the MRPV systems

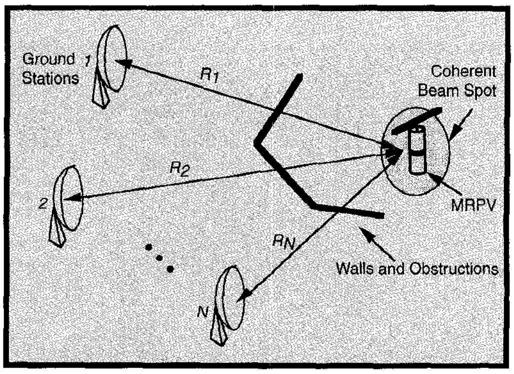


Fig. 3 Multiple ground station configuration

the system; the control surfaces are warped by applying the proper voltages to the materials.

Microwave power transmission

One possible arrangement of a microwave powered MRPV system is shown in Fig. 3. One or more ground stations would generate a cw signal which is fed to an antenna pointed in the direction of the RPV. The equation governing the power received by the vehicle, P_r is essentially the same one that describes the received signal in a communication system. The total power received at the vehicle when the signals from N ground stations are added coherently is

$$P_r = \frac{A_{er}e_{dc}}{4\pi}\left|\sum_{n=1}^{N}\frac{\sqrt{P_{tn}G_{tn}e_{wn}}}{R_n}\right|^2$$

For ground station n, the transmitter power is P_{tn} and the antenna gain is G_{tn}. The product is referred to as the effective radiated power (ERP). Coherent summation implies that the received signal voltages are added, hence the square root in the numerator. A_{er} is the effective area of the MRPV antenna which is approximately independent of direction and, thus, equal for all stations. The range between station n and the MRPV is R_n. The two remaining factors in the numerator, e_{wn} and e_{dc}, are efficiency factors that account for the propagation loss due to obstructions and the conversion from cw to dc, respectively.

Using existing technology, it is estimated that 8 to 10 W are required after rectification to power the onboard systems. Given that there is a minimum received power for operation of the MRPV, the maximum range of the vehicle is primarily determined by the total ERP.

The transmit gain is proportional to the antenna area. However, the antenna area is limited by the requirement that the ground station equipment be portable. The transmitter power cannot be increased indefinitely either. After a point, the prime power and cooling requirements become prohibitive. Also, the power density in the vicinity of the antenna feed becomes large enough to cause arcing.

To achieve the maximum benefit from multiple ground stations, all the incoming waves must be phase synchronized at the MRPV. Phase locking the sources would not work because the paths from the individual ground stations vary; they are at different ranges and the signals encounter different obstructions. Even though the waves would be in phase leaving the transmit antennas, they would probably not be in phase at the RPV antenna.

A method called *beam tagging* can be used to synchronize the signals at the MRPV. It is based on the fact that the total received signal can be maximized by adjusting the individual ground station signals sequentially. This is accomplished by coherently summing the signals from all ground stations with phase shifted or frequency modulated versions of the one being adjusted. A comparison of three measured signals can be used to find the phase necessary to maximize the total signal at the MRPV.

The disadvantage of this method is that it takes time. Three round-trip measurements must be made for each ground station, and the power transmission is interrupted while the measurements are being taken. In spite of these disadvantages, the beam tagging method has been used successfully to power an aircraft.

The effect of building walls and other obstructions has also been examined analytically and verified experimentally. The transmitted power though thick concrete walls can be more than an order of magnitude below the incident power. This loss must be overcome by increasing the transmitted power. When multiple ground stations are used, the power from each can be adjusted independently to maintain a constant spot intensity. If one beam passes through a thick wall, the power in the remaining beams can be increased to compensate for the loss. The wall losses increase with frequency, and, thus, maximizing e_{wn} favors the use of lower frequencies. Commercial MRPVs would probably operate in the scientific and commercial band around 2.45 GHz.

Radiation hazards

Focused high power microwave beams present a potential radiation hazard. There are several measures of radiation exposure and absorption. They include the peak power density in Watts per square meter and the specific absorption rate (SAR) in Joules per cubic meter. The currently defined safe levels are a function of frequency.

At microwave frequencies, the body is a relatively good conductor, and most of the incident energy is reflected. The peak power density that can be tolerated is primarily determined by sensitive organs such as the eyes.

The highest power density encountered during operation of the MRPV will occur at the coherent spot where the individual ground station beams converge. Simulation of the MRPV flight shows that the safety standards can be met under all conditions at short ranges if power management is incorporated. That is, the smallest possible value of P_t is used that provides the minimum required P_r.

The main safety problem occurs when the MRPV operates at longer ranges which requires high transmit power. Thus, it is the safety limitations that may ultimately limit the MRPVs operational range when personnel are

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present. As the MRPV size becomes smaller, it will require less power and therefore be capable of increased range for a fixed transmit power.

MRPV prototype

Several companies will be involved in the next phase of the MRPV development. The primary objective will be demonstrating untethered controlled flight. Fundamental aerodynamic, control, packaging, and weight reduction strategies will be validated. The size of the prototype is expected to be approximately 6 inches by 2 inches.

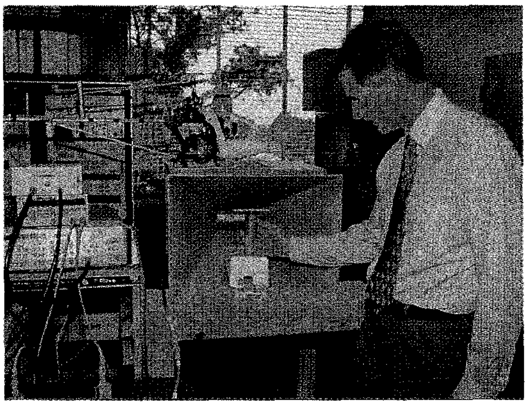
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Fig. 4 The MRPV prototype

At the Naval Postgraduate School, free space power transmission was demonstrated using such a prototype, shown in Fig. 4. Important elements of the microwave system were developed, including the rectifier circuitry and the vehicle antenna. In order to keep the transmit power low, the prototype is placed in the aperture of a horn antenna. Thus, it avoids the $1 / R^2$ power spreading loss. The operating frequency is 1 GHz. The power radiated by the horn is approximately 0.5 W, less than the transmit power of a cell phone. Future work will include demonstrating that the MRPV can be powered by an existing shipboard radar.

Micro RPVs hold great promise in a variety of environmental, law enforcement, military, and search and rescue applications. This is particularly true if the cost per vehicle can be reduced so they are expendable without too much anxiety. Fortunately, steady improvements are being made in all of the relevant technologies. This reinforces the optimistic outlook for the future of miniature RPVs.

About the author

David C. Jenn received his BSEE from the University of Wisconsin, Milwaukee, his MS from the Ohio State University, Columbus, and his Ph.D. from the University of Southern California, Los Angeles.

From 1976 to 1978 he was with McDonnell Douglas Astronautics Company in St. Louis. In 1978, he joined Hughes Aircraft Company, Fullerton, California. Most recently his work was devoted to integral equation solutions to antenna and scattering problems. In 1990 he joined the Department of Electrical and Computer Engineering at the Naval Postgraduate School in Monterey, California as an Associate Professor.

Dr. Jenn is the author of numerous journal papers, symposium papers and short courses. He is also author of the book, *Radar and Laser Cross Section Engineering.*