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OVERVIEW

NASA's upcoming lunar campaign calls for the incorporation of a lander-mounted transceiver operating at microwave frequencies for the exchange of data between a lander and mobile astronauts, as detailed in [1]. With a current best range estimate of only 0.5 km, the extent of exploration on the lunar surface is truly limited by the current transceiver architecture. In order to increase this system's range and thus the operational radius of human excursions, a new antenna system having high gain and employing innovative techniques leading to high efficiency must be selected.

Possible range-extending solutions include highly optimized omnidirectional radiators such as tuned dipoles and monopoles, the relatively nascent microstrip antenna, and phased arrays. This paper will explore characteristics of these modern microwave antennas for use in a short-range lunar communications system, with an emphasis on tradeoffs and common performance enhancements for each.

DIPOLE ANTENNAS

Center-fed (CF) dipole. As detailed in [2], CF dipole antennas are among the most popular antennas for their simple design, favorable input impedance (when tuned), and near-unity radiation efficiency for most materials. The quintessential dipole is the CF half-wave, which features a purely real input impedance (73 Ω) and a directivity (D) of 1.64. This is slightly greater than a CF short dipole (D = 1.5), but inferior to a CF full-wave dipole (D = 2.41). The maximum achievable D for a CF dipole is one of length 1.25λ (D = 3.27).

One particular advantage of the CF half-wave dipole is its purely real input impedance, which simplifies matching networks. The full-wave dipole, however, features an infinite (capacitive) input reactance, which would require very large-valued matching elements to counteract reflections. The 1.25λ dipole also has a large albeit far smaller input impedance. Thus, a tradeoff between directivity vs. input impedance is a crucial tradeoff when selecting a dipole.

Because dipoles are resonant structures, they suffer from low bandwidth. However, in general, bandwidth increases with conductor radius. If cylindrical wires are used, then simply increasing the gauge results in a bandwidth increase. For printed dipoles (metallic strips as seen in MMICs), an equivalent operation would be to widen the strips. The accompanying tradeoff for bandwidth would be ohmic losses, and thus antenna efficiency.

Vee dipole. The "vee" dipole (so-called because of the arrangement of the antenna arms into a "V") achieves greater directivity than its straight dipole counterpart, albeit is azimuthally asymmetric. It has generally lower input impedances than the straight dipole.

Folded dipole. Among the most popular variations of the dipole antenna is the folded dipole, as described in [3]. This structure resembles a "compressed loop" and has current nulls at the rounded ends. It features an input impedance of four times that of a straight wire dipole, which is essential for applications in which the feed is a 300 Ω twin-lead transmission line. In addition, folded dipoles generally feature wider bandwidths and higher structural rigidity than their straight-wire counterparts.

Sleeve dipole. A dramatic increase in bandwidth can be attained by the use of sleeve antennas. This technique can be applied to dipoles or monopoles, and approximates a conductive sheathe at the antenna feed point, which acts to extend the antenna resonance and increase its effective Q. Sleeve antennas are often realized in the "open sleeve" configuration treated in [4], which sandwiches the antenna feed between two conductive elements of calculated size and proximity.

Dipole with ground plane backing. If a unidirectional pattern is desired, ground plane backing can be used to confine radiation to the half (or quarter) space, increasing gain. The ground plane acts as a reflector, with resulting gain primarily affected by the antenna's proximity to it. Even higher gain can be realized using a "corner reflector" arrangement of ground planes, which per [4] yields a 10-12 dB gain increase over the standard half-wave dipole. The disadvantages of using ground plane backing include the halving (or quartering) of space accessible to the main beam, as well as increased ohmic losses (in the ground planes).

Balun enhancement for dipoles. When the feed for a dipole (or monopole) is a coaxial transmission line, a current asymmetry can arise along the antenna arms, which results in nonideal radiation pattern. This phenomenon can be compensated for with the use of a balun, which regulates the sheathe current and forces equal currents on both antenna poles, as shown in [5]. The balun's primary operation can be described as an "impedance transformer", which matches the differing impedances of the antenna and transmission line. Disadvantages of baluns include high ohmic losses (signal attenuation), cost, and complexity.

MONOPOLE ANTENNAS

The most attractive feature of the monopole antenna is its smaller form factor compared to a dipole. At half the size of a dipole, the monopole produces a similar radiation pattern, albeit only in the upper half-space. A key requirement for a monopole is the presence of a ground plane to produce a virtual current, as described in [2]. Nonidealities arise in the pattern of a monopole the smaller the ground plane. A notable example of this is the increasing inclination of the main lobe as the ground plane size decreases. This could prove unfavorable in the case of a monopole antenna mounted to the top of a lander: the direction of maximum radiation would likely be above the horizon, resulting in wasted power.

MICROSTRIP ANTENNAS (MSAs)

The MSA, also known as the patch antenna, is a relatively new antenna element that is frequently finding new applications in today's communications systems, especially those operating in VHF and higher frequencies (e.g. Wi-Fi). The MSA consists of a flat metal "patch" on top of a ground plane, separated by a dielectric substrate, as shown in [6]. Among its greatest benefits are low profile and easy manufacturability: one (or several) MSAs can be printed on the same monolithic microwave integrated circuit (MMIC). Operationally, the MSA leverages fringing fields at its sides to produce a z-directed radiation pattern.

Although often square, both dimensions of MSAs can be scaled to optimize impedance and efficiency (the thickness is not too important). MSAs also feature radiation confined to the half-space; as such, a well-sized patch can have a directivity as high as 5. Patch antennas are commonly "edge-fed" with either quarter-wave transformers or "insets" (to tune input impedance). In addition, coaxial "probe-fed" feeds can be realized at the cost of radiation pattern degradation (due to radiation of coax). As a resonant antenna, the MSA exhibits a narrow bandwidth. Bandwidth can be improved by using electromagnetically coupled or aperture coupled feeds as described in [7], with the latter robust but complicated to manufacture.

ARRAY ANTENNAS

Array antennas, also known as phased arrays, utilize pattern diffraction and variable phasing of multiple antennas to produce highly directive, electrically-steered radiation. For one-dimensional (e.g. azimuthal) scanning, a linear array is required. The antennas are spaced equally and fed currents of varying phase to produce a "total array pattern" in a direction of interest. Gain varies as a function of steered angle, constrained by the element pattern shape as well as variable mutual coupling between array elements, as characterized in [8]. Among the most popular array elements are dipoles (often with ground plane backing) and MSAs. Both exhibit wide beamwidth and the ability to be printed on an MMIC.

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