Quadrifilar Helical Antennas for Personal Satellite Terminals

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The Quadrifilar Helical Antenna (QHA) is an excellent choice for personal handsets that communicate with satellites. The QHA is capable of illuminating a considerable portion of the upper hemisphere. It provides omni-directional coverage in azimuth with an ability to tailor the pattern for the expected elevation angles to the satellite.

Generic Mobile/Personal QHA

Near Resonant Balanced Structures Including Matching Networks Work Best

The QHA, while typically fed as an unbalanced antenna, is best considered a balanced structure. Opposing filars tend to form a dipole like structure, while the opposite pair of filars forms a second dipole like structure. The two separate pair of filars fed in phase quadrature form a hemispheric circularly polarized radiation pattern. The QHA is self-sufficient without a counterpoise. Best performance is achieved if the antenna is isolated by itself, but that does not satisfy the needs of most mobile or personal applications. So, as in many antenna applications, the antenna is forced to work in a compromised manner.

Some aspects of circular polarization are important to understand for this application. An incident right hand circularly polarized (RHCP) signal is reflected, or bounced, as a left hand circularly polarized (LHCP) signal. For instance, this occurs when the QHA is mounted on top of a counterpoise or ground plane. Suppose a QHA is mounted on the top center of a car roof. Desired RHCP signals glancing off the car roof become LHCP. Therefore, the LHCP reflected signal does not contribute to the power induced into the RHCP antenna. There may be additional concerns for systems that transmit RHCP to some customers and LHCP to others because the undesired polarization could become an interfering signal.

Noise, on the other hand, is not affected by about polarization in the same way. Noise induced into the antenna is contributed from the total antenna pattern, not just the right hand component. Noise from a counterpoise bounce would have an effect on the antenna noise temperature. For this reason, ground planes underneath the QHA can have a detrimental effect on the performance of the antenna.

In order for an antenna to deliver power either to the receiver or to radiate power from the transmitter efficiently, the antenna radiating structure together with its matching network should be matched to the connected receiver or transmitter. In the art of antenna compromise, it is sometimes necessary to augment a not quite resonant radiating structure with a good matching structure.

Multiples of Quarter-Wave Element Length Work Best

Characteristically, we have learned to think of resonant antennas in terms of multiples of quarter-wavelengths. For the QHA, larger multiples tend to increase the gain at the peak of the beam. Quarter-wavelength element or filar length QHAs tend to have lower gain compared to half-wave filar antennas and exhibit narrower bandwidth. Higher multiple quarter-wavelength QHAs can be made to direct the peak of beam for specific applications. In some cases beam widths less than hemispheric are desired.

Need to Reduce Lower Hemisphere Radiation

Higher multiples of quarter-wavelength elements tend to improve the front hemisphere to back hemisphere ratio. This can be important in some applications to reduce the noise temperature of the antenna.

Pitch Angle and Diameter are the Next Most Important Dimensions

Consider a mobile terminal at 45 degrees latitude on earth. The user typically has the QHA pointed at the local zenith. The peak of the beam would like to be at an elevation angle less than 45 degrees for all azimuth angles. Half-wave, three-quarter wave, or five-quarter wave antennas can be tailored for beam peaks at desired elevation angles.

The pitch angle of the QHA tends to control the beam width and the elevation for the peak of the beam. Low pitch angles produce higher gain at the zenith. Higher pitch angles tend to allow the peak of beam to occur at lower elevations angles while maintaining that peak for all azimuth angles. An interesting side note is that higher pitch angle QHAs have broader bandwidth. The balanced and essentially resonant conditions for satisfactory circular polarization are generally narrow bandwidth structures. Tighter wound, lower pitch angle QHAs have narrower bandwidth than higher pitch angle QHAs.

Smaller, Lighter, Cheaper, Faster, Better

For today's communications products, the customers' applications tend to always require smaller, lighter, cheaper, better performance in a faster development time. Thus the antenna performance must be attempted for less than ideal size. For instance, in most applications, a 50-Ohm characteristic QHA structure would have a larger diameter than is considered acceptable. A better antenna could be made if a three-quarter filar length could be used, but the overall antenna length may be too long for the customer preference. The real game seems to be to develop QHAs and other antennas to work well in spite of the imposed working conditions.

The QHA can be thought of as a quadrature fed transmission line. For odd quarter-wavelength filars, the transmission line behaves as an open circuited radiating line. For even quarter-wavelength filars, the transmission line behaves as a short-circuited radiating line.

Narrow diameter QHAs have low characteristic impedance, significantly lower than 50 Ohms. These values range from 3 Ohms to 15 Ohms at resonant equivalents. Most personal communication product manufacturers want narrow diameter antennas, so it is necessary to deal mostly with low driven impedance factors.

Factors for Satellite Communications

Antenna Temperature

The antenna for personal or mobile earth terminals such as telephone handsets is subject to noise received by the antenna and the receiver added noise. The antenna noise temperature is the result of integrating the three-dimensional antenna pattern with the incremental noise temperatures over spherical space. Typically, the noise temperature varies with elevation angle. The noise temperature below the horizon may be considered as 300 K. The noise temperature at the local zenith may be less than 5 K. Low on the horizon, the noise temperature varies from 300 K at the horizon to 100 K at very low elevation angles near the horizon to 5 K near the zenith. For low link margin communications systems, it is generally important to minimize the antenna temperature. Therefore, a beam width somewhat less than 180 degrees tends to lower the antenna noise temperature.

Receiver Temperature

The receiver noise figure or noise temperature is an important factor in determining the performance. In the following section, the G/T figure of merit demonstrates the importance of antenna gain, antenna noise temperature, and receiver noise figure contribute to the G/T figure of merit. Critical knowledge of system parameters can help determine the importance of setting adequate requirements for system link margin performance.

G/T Figure of Merit

For personal or mobile earth terminals, one of the key performance parameters is the ratio of the receive antenna gain to the antenna noise plus receiver noise temperature ratio. This ratio is independent of modulation type or information bandwidth. This G/T ratio, normally expressed in decibels, is quite important for the communications system link budget.

Example:

The object of this example is to calculate G over T figure of merit. A graph is presented to show a range of antenna sky temperature and receiver noise figures.

$T_A := 175 \cdot K$ Antenna noise temperature, baseline value

$T_o := 300 \cdot K$ Ground temperature, in Kelvin

$NF := 3.5 \cdot dB$ Receiver noise figure in dB, a baseline value for discussion purposes.

$T_R := \left(10^{\frac{NF}{10}} - 1\right) \cdot T_o$ $T_R = 371.6\,K$ Receiver noise temperature in Kelvin

$T_{sys} := T_A + T_R$

$T_{sys} = 546.6\,K$ Receiver system noise temperature in Kelvin, baseline value

$G_{dB} := 2 \cdot dB$ Gain of receiver antenna expressed in decibels relative to a right hand circular polarized isotropic source. This gain is the minimum at the low elevation limit, currently specified at 45 degrees.

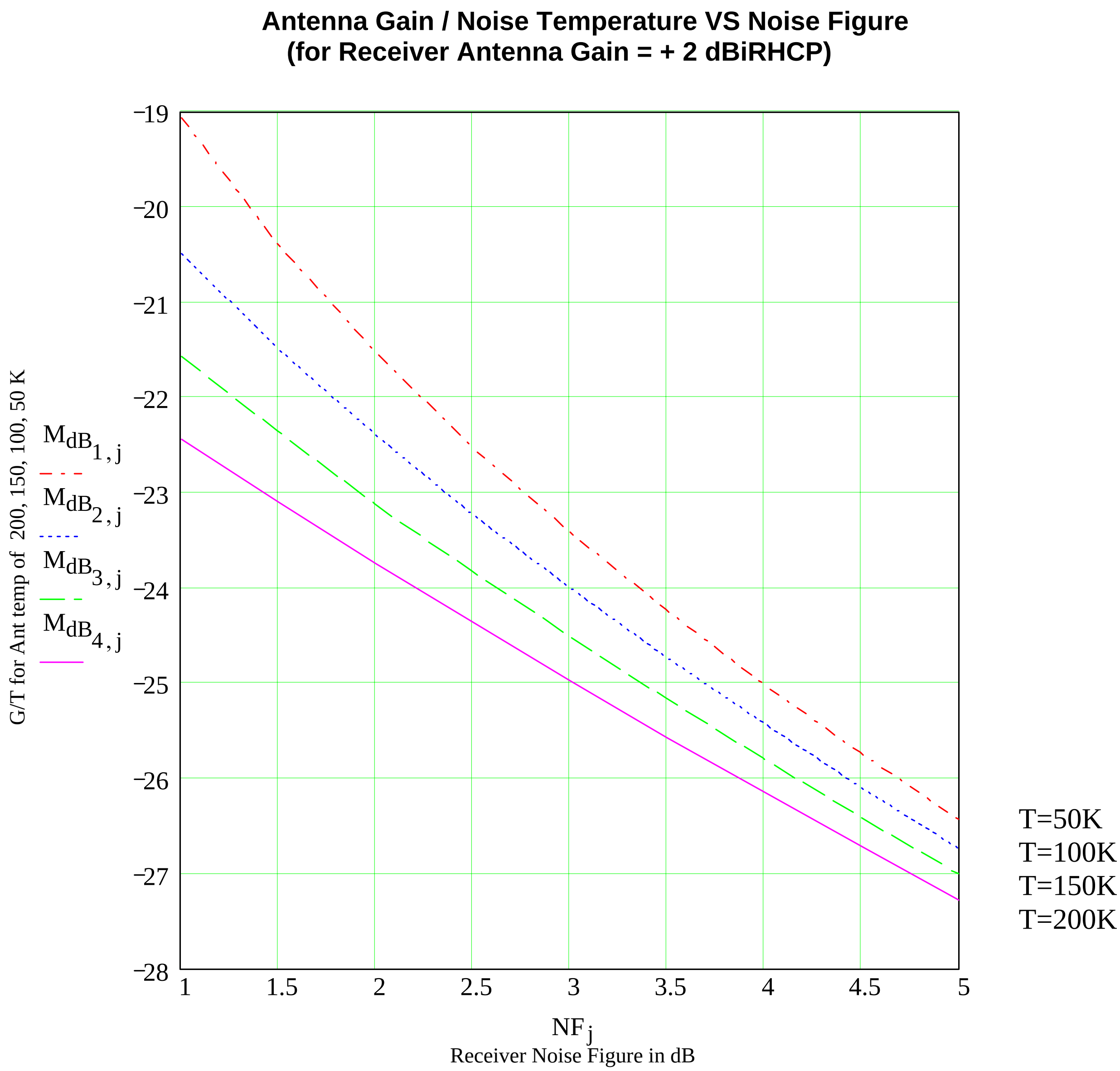
$G := 10^{\frac{G_{dB}}{10}}$ $G = 1.6$ Gain of receiver antenna expressed in linear terms

M is the G over T figure of merit for a satellite receiver. It is the ratio of the receiver antenna gain to its equivalent noise temperature. The units of "M" are per Kelvin. For convenience the satellite industry speaks of the G over T ratio in "dBK" units.

$M := \frac{G}{T_{sys}}$ $M = 0.0029\,K^{-1}$ G over T, expressed as a linear ratio

Logarithms are ratios, implying the units of the numerator cancel with the units of the denominator. The logarithm of the G over T ratio requires division by 1/K to properly cancel the units. Then a unit named "dBK" is created to apply to this situation.

$M_{dB} := 10 \cdot \log\left[\frac{M}{\left(\frac{1}{K}\right)}\right]$ $M_{dB} = -25.4\,dBK$ G over T figure of merit, baseline



General Principles

The general principles discussed in this paper have been used to develop a proprietary design for a satellite QHA aimed at the commercial market. The features and specifications are summarized in S-DMB product specification sheet.