NEW DESIGNS FOR DUAL BAND ANTENNAS FOR SATELLITE-MOBILE COMMUNICATIONS HANDSETS

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ABSTRACT:

The design of dual-band antennas for hand-held terminals (HHT) to be used in personal communications via a satellite network (SPCN) is investigated. The quadrifilar helical antenna (QHA) is selected as the optimum design for further study and a new design for a QHA is derived and optimized using a standard Moment-Method program. A dual L-S band design with an input VSWR in its two operating bands of between 1 and 2 was developed, incorporating external shorted turns to achieve the desired passbands. The design of the required hybrid feed phasing network is derived. Experiments with physical realizations of the optimum designs showed good performance and confirmed the computational predictions.

1. INTRODUCTION

The Quadrifilar Helical Antenna (QHA) is *an ingenious* antenna invented by Kilgus [1] in the 1970s. It consists of four coaxial helices rotated 90° with respect to each other (Fig. 1). The four helical elements are connected by short radial arms and are fed with identical signals, differing only by sequential 90° phase shifts (i.e. 0°, 90°, 180°, 270°). The analysis by Kilgus [1] for the resonant QHA (RQHA) is based on the assumption that the QHA consists of four helical and four radial parts. The analysis approach to the RQHA is based on the viewpoint that a QHA consists of two bifilar helices (BH) placed at 90° angular displacement and fed in phase quadrature. The radial segments at the distant end can be shorted or open circuited, giving only changes to the input impedance.

This antenna has the useful property of producing a single main lobe from a structure of modest electrical size (i.e. that fits in an electrically small envelope). It is thus attractive for application in mobile satellite terminals.

One of the major disadvantages of the QHA is the complex feed network that it requires. One approach is to feed each BH with the assistance of a balun, most configurations also needing a 90° phase shifter. The exceptions to this are the self-phased configuration and the Keen balun [2], which can provide the phase difference without a hybrid and with the use of only one balun. The other way is to feed each of the four helical elements separately, with appropriate phases, using three hybrids. This method does not require a balun to feed the QHA.

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2. DESIGN PROCEDURE OF QHA AND HYBRID FEEDING NETWORK

A quadrifilar helix that requires a separate phasing network at the input is known as an externally phased quadrifilar helix. Fig. 1 shows a quadrifilar helix fed from the bottom. This type of antenna requires a network creating the appropriate phases and matching the impedance of the elements to the coaxial feed line. A simple phasing network of 3 dB hybrids can be used to produce equal amplitude signals with quadrature phasing to the radiating elements.

The radiating helical elements determine the pattern characteristics and the shape. The element dimensions have been empirically determined by many authors *[3-5]* to accord with satellite system specifications. The feeding direction relative to the main lobe can be arranged to be either forward-fire or backfire by changing the phase sequence of the elements. The axial ratio of the main beam radiation is controlled by the length and diameter of the helix, and the symmetry of the elements. The phasing circuit plays an important role in generating a shaped conical pattern, which is *required* for many mobile satellite system applications. The sense of the polarization is controlled by the winding direction of the helices.

2.1 DUAL BAND DESIGN

For dual-frequency operation, a single QHA is not feasible, because it is a resonant-type antenna and is inherently too narrow-band. Therefore, dual-band operation can only be achieved through the incorporation of two antennas into one structure by coaxially mounting them in either an enclosed (QHA-1 inside QHA-2) or a piggyback (QHA-1 on top of QHA-2) fashion [4,5]. For ease of manufacture and minimized antenna cross-section, the piggyback design was chosen. In addition, a third short external set of helices (QHA-3) was introduced to optimize the VSWR for the second operating frequency band by acting as a set of tapping windings. Table 1 shows the data for the forward-fire QHAs found to be optimal.

Table 1: Dimensional Data for dual-band end-fire QHA.

QH no.	***Spacing between turns (m)***	***Wire Radius (m)***	***Helix Radius (m)***	***Number of Turns (N)***	***Axial Length (m)***	***Length of one Element (m)***
1	0.028	0.00089	0.007	1.25	0.035	0.0652
2	0.068	0.00089	0·007	1.25	0.085	0.1012
3	0.068	0.00089	0.007 top 0.0105 bottom	0.25	0.017	0.0217

All the QHAs were designed for minimum VSWR (between 1 and 2) over the dual L and S band satellite-mobile frequency ranges (approximately 1.61-1.63 GHz and 2.47-2.5 GHz for SPCN services). The objectives were to achieve maximum power gain (greater than 5 dB [3]) and an axial ratio close to unity over elevation angles from zenith to ±60°. *The handset is box-shaped and its height was kept constant at 14 cm (a typical value for current satellite-mobile handsets*). To ease installation of the phasing network and subsequent testing, the dimensions of the top plate were taken to be 6cm × 6cm and the antenna was optimized with this.

The hybrid phasing networks for the QHA was constructed on high permittivity ($\varepsilon_r = 10.2$) substrate for operation at 1.62 GHz and 2.48 GHz. The design was optimized *for both bands subject to a VSWR ≤ 2.*

The simulation of the forward-fire QHA and handset for dual L/S bands was performed using NEC-WIN Pro [6], while the hybrid phasing network was designed using the Libra package [7]. A wire grid representation of the design is shown in Fig. 2. The handset box was represented by a mesh of 18 × 8 × 8 wires, each being a single NEC segment; the radius of the wires was chosen in accordance with the equal-area rule. The QHAs were represented using the NEC GH (Geometry – Helix) command, the number of segments per single helix being 30, 30 and 3 for QHA-1, 2 and 3 respectively. *Four voltage sources are used for excitation; each one of them is placed at the attachment mode of each helix to the top of the box.* The simulations were stable *for two values of grid size in the handset box model and segment size in the helices* and the run times were a few *minutes per fre*quency when using a 400MHz Pentium-II computer with 256 Mbyte RAM.

Although it is known that modeling of helices can sometimes cause stability problems with MoM programs, no such problems were experienced in this case. This is presumed to be due the relatively large pitch of the helices used, which thus avoided large values of mutual coupling between turns.

3. RESULTS

The computed axial ratio and power gain (at 1.620 GHz and 2.480 GHz) of the proposed antenna are shown in Figs. 3 and 4 respectively. The attenuation of the main beam (relative to boresight) at ±60° is seen to be about 3dB at 1.620GHz and 7dB at 2.480GHz: the latter figure is rather high but manageable within a typical link budget. The axial ratio remains greater than 0.9 over the ±60° range at both frequencies.

The prototype antenna was manufactured from copper wire, supported on acrylic struts distributed radially, at each turn, from a central acrylic rod (Fig. 5). The wires entered the copper case through separate SMA connectors. The hybrid phase networks were fabricated within the two bands of interest on substrate having $\varepsilon_r = 10.2$ and a thickness of 1.27 mm. The prototypes of the hybrids are shown in Fig. 5, with the dummy handset and prototype antenna. The measured performance of the hybrid phasing networks at 1.620 GHz and 2.480 GHz are given in Tables 2 and 3 respectively.

Table 2: Measurement results for hybrid phasing network at 1.62 GHz.

Port Number	*Target phase (degrees)*	*Measured phase (degrees)*	*Insertion Loss (dB)*	*Return Loss (dB)*
1	0	0	-6.27	-17.0
2	90	88.9	-6.74	-18.2
3	180	178.1	-6.09	-18.2
4	270	268.2	-6.63	-18.5

Table 3: Measurement results for hybrid phasing network at 2.48 GHz.

Port Number	***Target phase (degrees)***	***Measured phase (degrees)***	***Insertion Loss (dB)***	***Return Loss (dB)***
1	0	0	-6.05	-14.2
2	90	89.2	-6.96	-15.5
3	180	178.1	-6.38	-14.5
4	270	268.8	-6.69	-15.4

The results agree well with the desired values *required for feeding*. The small size of the hybrid phasing networks allowed them to be inserted easily inside the handset. The measured VSWR and the input impedance as a function of the frequency at the input of the hybrid networks when connected to the antenna within the handset are shown in Figs. 6 and 7 respectively. The results are quite encouraging and in line with the expected VSWR pass-bands.

An initial measurement of axial ratios (Fig. 8) showed a degree of agreement with the predictions (Fig. 3), although there was some degradation, believed to be due to deficiencies in the test facility.

CONCLUSIONS

A dual-band quadrifilar helical antenna (QHA) was designed and analyzed. It consists of two sets of four coaxial helixes, each helix rotated 90° with respect to its neighbors in each set. The realization adopted in the present work used a bottom-fed (end fire) version for convenience in feeding. The helices were fed with a sequential phase difference of 90 degrees, with the sense of the phasing relative to the helix senses controlling whether the antenna radiates in forward-fire (end-fire) or back-fire mode. By using two sets of QH groups, combined in 'piggyback' fashion, plus a small additional set of QH matching stubs, it was possible to achieve good matching over the two desired operating bands (satellite-mobile allocations in the L and S bands). The computed results showed end-fire (zenith-directed) patterns for the two operating frequencies, having the desired beamwidth of around 120° and an axial ratio close to unity across the beam. The measured results showed good agreement with the theoretical predictions in the sense of minimum VSWR and matching to a 50Ω source in the two operating bands. A preliminary measurement of axial ratio showed an encouraging degree of agreement with the predictions.

MoM modeling using NEC was found to operate stably and reliably in this case, despite the adoption of multifilar helical antennas. This gives confidence in the use of this method for other electrically-small helical antennas, as are now popular in mobile communications handsets. However, incorporation of the interaction with the human head would be desirable, but thus would require a hybrid formulation with a differential-equation method, since use of MoM for large inhomogeneous dielectric volumes is not feasible. This has already been implemented for single helical antennas [8] and work on its extension to QHA handsets is in progress.

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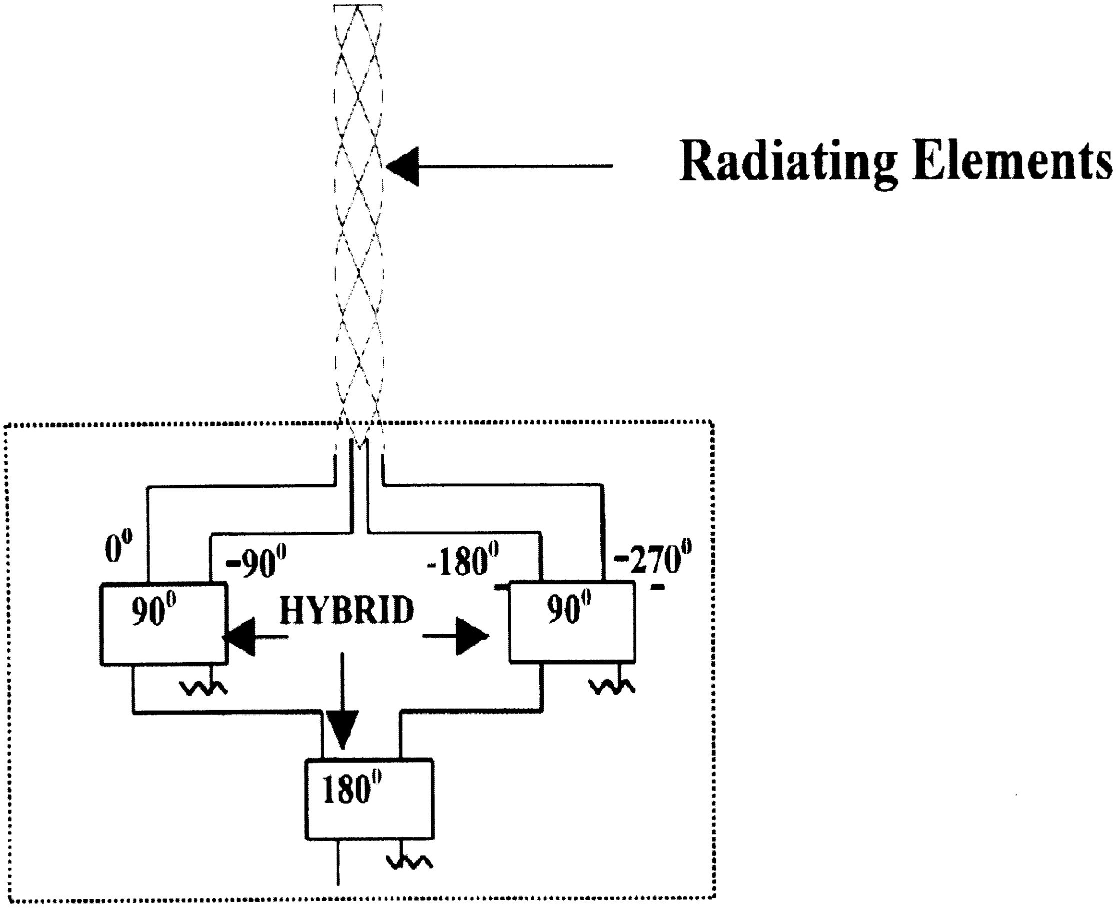


Fig. 1 Conceptual phasing network for an end-fire QHA.

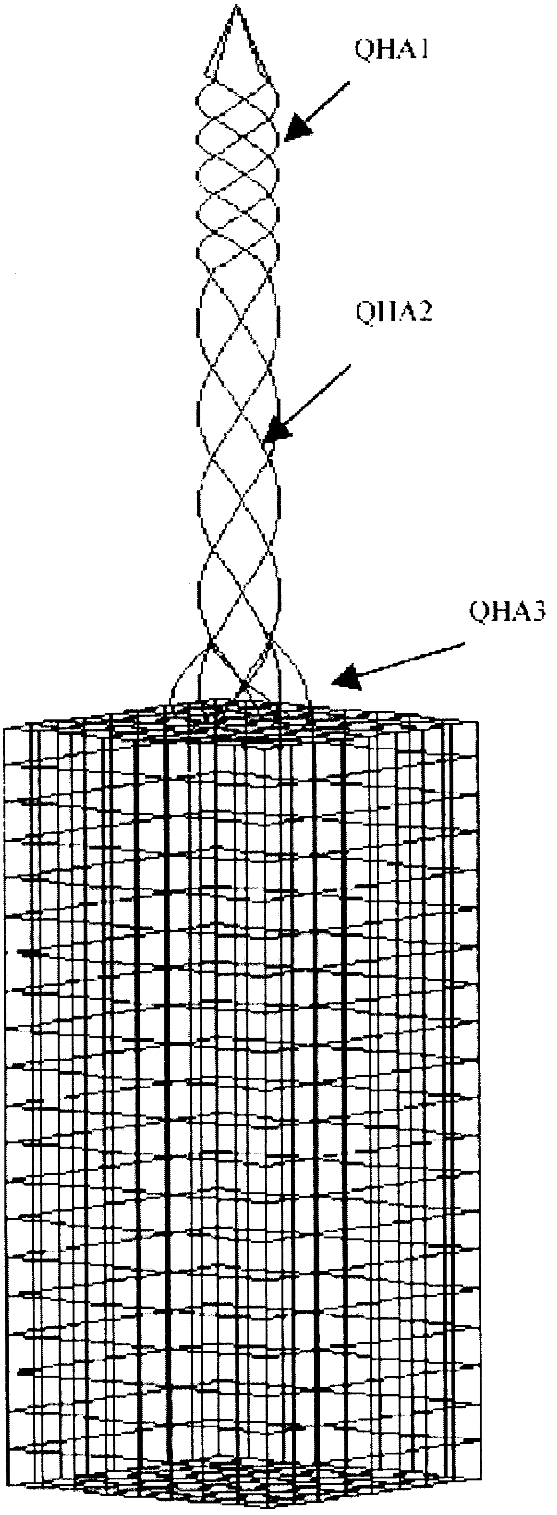
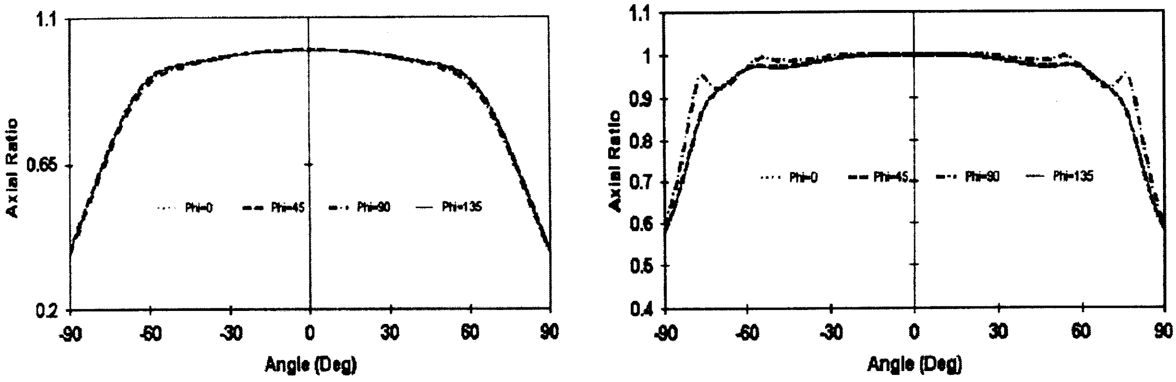
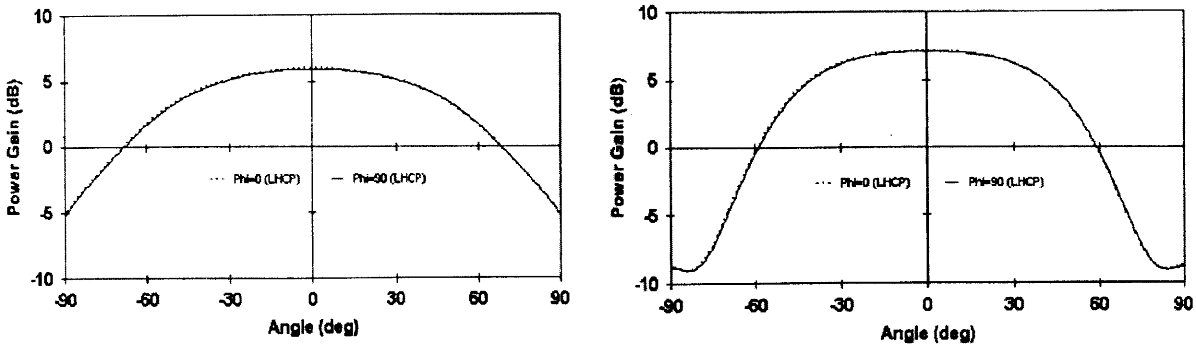


Fig. 2 Wire grid geometry model of dual band QHA and dummy handset, as used in NEC-WIN Pro.



(a) (b)

Fig. 3 Axial Ratio over main beam (a) at 1.62 GHz; (b) at 2.48 GHz.



(a) (b)

Fig. 4 Radiation Pattern Power Gain (a) at 1.62 GHz; (b) at 2.48 GHz.

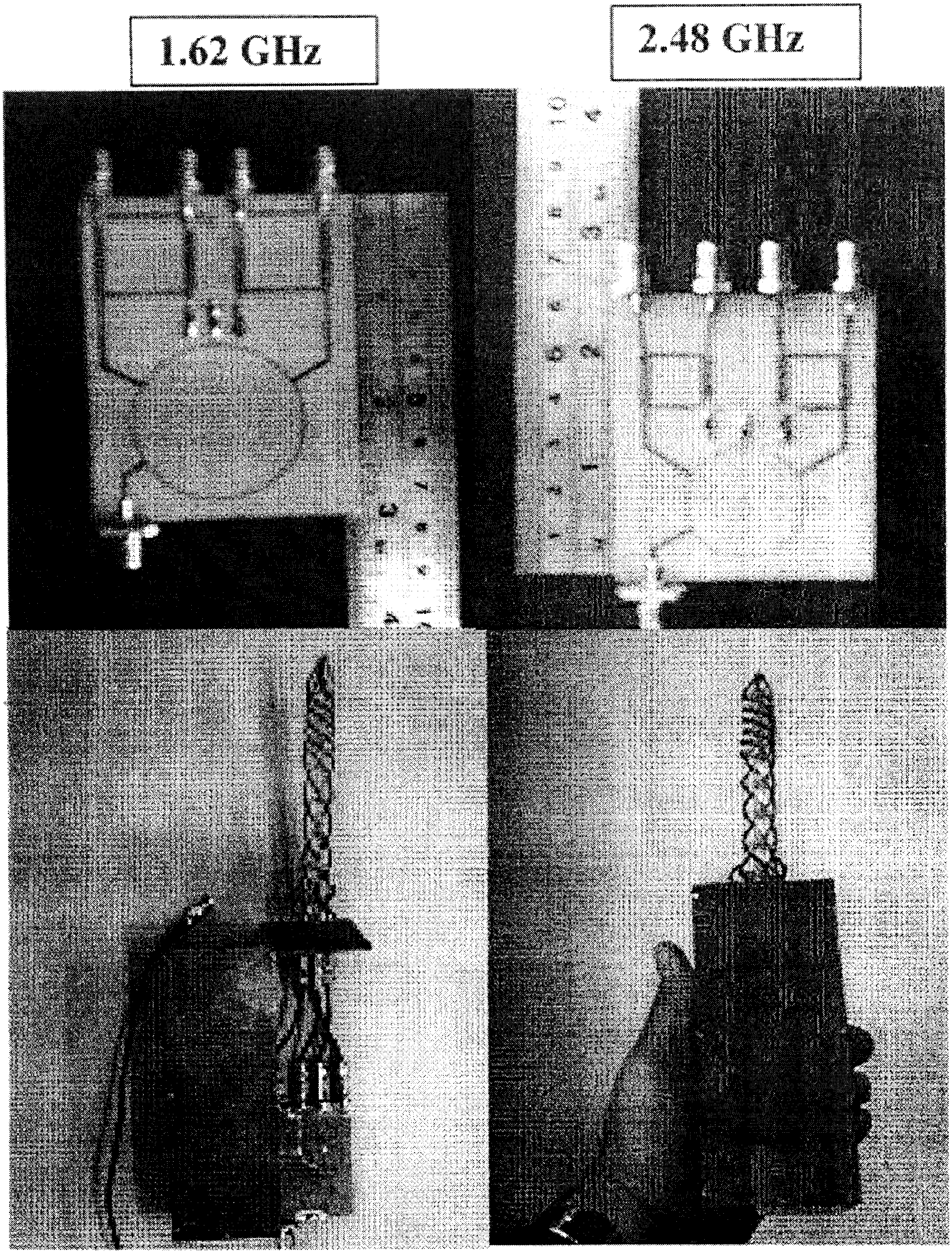
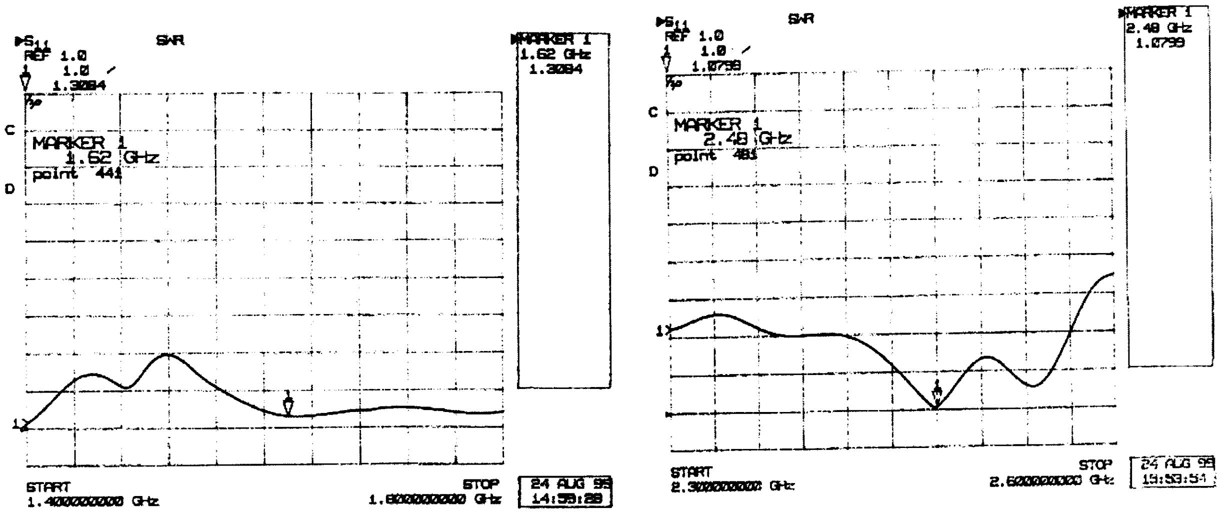
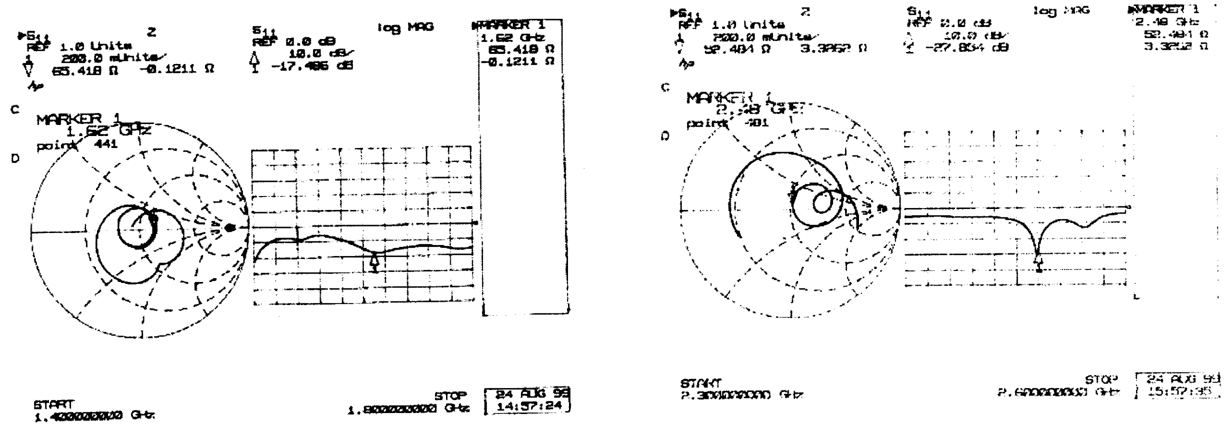


Fig. 5 Photographs of the QHA for dual L-S band, with dummy handset and hybrids.



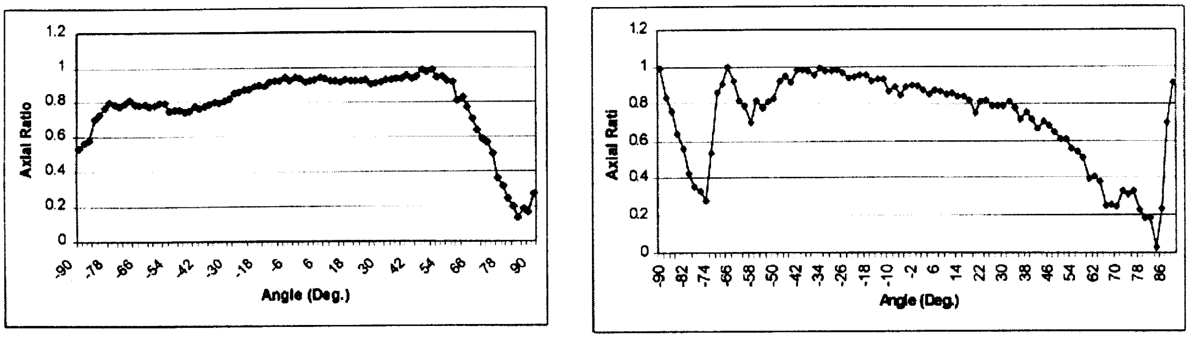
(a) (b)

Fig. 6 The measured VSWR as a function of the frequency at the input of the hybrid network (a) at 1.62 GHz; (b) at 2.48 GHz.



(a) (b)

Fig. 7 Smith chart for the input impedance and return loss of the antenna located at the input of a hybrid network (a) at 1.62 GHz; (b) at 2.48 GHz.



(a) (b)

Fig. 8 Preliminary test results for axial ratios (a) at 1.62 GHz; (b) at 2.48 GHz.