Design of Broad-Band and Dual-Band Antennas Comprised of Series-Fed Printed-Strip Dipole Pairs

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***Abstract*—The design of antennas consisting of two strip dipoles the arms of which are printed on opposite sides of an electrically thin dielectric substrate and connected through a parallel stripline is presented. The antennas are designed to have broad-band or dual-band capability suitable for application in base stations of wireless communication systems. An important advantage of these antennas is their simple structure, allowing them to be readily manufactured as printed circuits. Broad-band antennas with bandwidths greater than 30% for $VSWR \leq 1.5$ operating near 2.0 GHz and dual-frequency antennas operating at 0.9 GHz/1.5 GHz and 0.9 GHz/1.8 GHz bands are presented.**

***Index Terms*—Base station antennas, broad-band operation, dual-band operation, printed strip dipoles.**

I. Introduction

Cellular communication systems have become very popular with a corresponding increase in the number of base stations. These commercial wireless communication systems generally require low-cost microwave components and antennas. Dipoles printed on an electrically thin dielectric substrate are commonly used as radiating elements in base-station antennas as they are low weight, easy to fabricate, and they also offer relatively wide bandwidths and high-polarization purity [1]. Printed dipole radiators have been popular candidates for phased-array antennas that contain many elements because of their suitability for integration with microwave integrated circuit modules [2]–[4]. Arrays of double-sided printed strip dipoles fed with corporate networks of parallel striplines and backed by conductor planes were developed for radar and various military applications [5], a portable cylindrical array antenna with 360° coverage [6] and arrays with large bandwidths [7]. Printed strip dipoles have also been considered for application in far-infrared and millimeter-wave imaging systems [8].

This paper reports on printed circuit antennas featuring broad-band or dual-band operation where constructional simplicity and low manufacturing cost are retained. The antennas consist of standard series-fed arrays of two strip dipoles realized in double-sided configuration (see Fig. 1). Although printed antennas have been primarily used to achieve a low-cost and lightweight source, the presence of the dielectric substrate can be used to help realize broad-band operation [9] and dual-band operation [10].

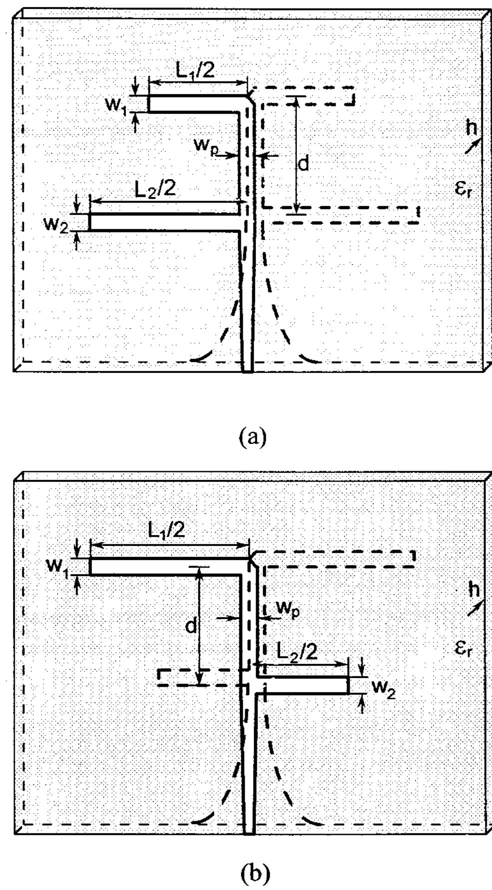

Fig. 1. Schematic drawing of (a) broad-band and (b) dual-band antenna of two series-fed printed strip dipoles.

Strip dipoles printed on electrically thin low-permittivity substrates behave similarly to ordinary dipoles and have often been designed based on experimental trial and error [4]–[7]. However, the antennas presented in this paper have a large number of design parameters making such a design approach unfeasible. For example, dipoles of different lengths are closely spaced and their radiation characteristics depend on the design of the connecting transmission lines. Two analysis techniques are applied to help design these antennas. One is a full-wave moment method in the spectral domain, similar to the approach used for analysis of strip dipoles printed on a grounded dielectric substrate [11]. In the other technique, the printed strip conductors are transformed to circular conductors coated with dielectric or magnetic covers based on the principle of quasi-static energy

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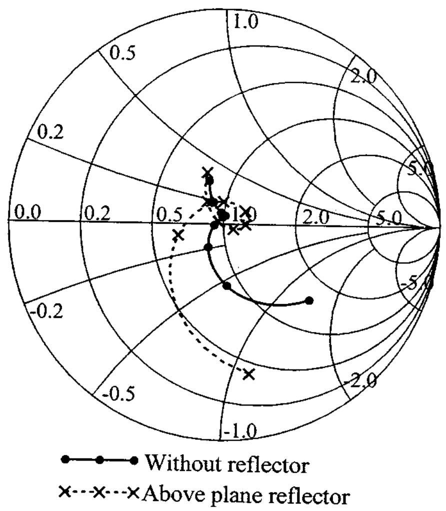

Fig. 2. Impedance locus of a broad-band antenna with and without reflector ($f = 1.6$–2.4 GHz with dots and crosses shown at frequency steps of 0.1 GHz).

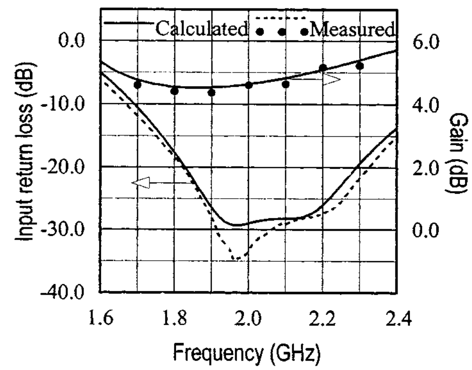

Fig. 3. Measured and calculated input return loss and gain of the experimental broad-band antenna without reflector.

equivalence [12], [13], with radiation properties then solved by the usual method of moments for wire antennas. This approach is much simpler and can be combined with a wire-grid model to treat printed strips placed above a finite ground plane. However, comparison with results obtained from the full-wave analysis shows that this approximate model is accurate only for narrow strips printed on an electrically thin substrate.

Methodology for the design of broad-band and dual-band antennas comprised of series-fed printed-strip dipole pairs is presented. The influence of various parameters on antenna characteristics is discussed. Results are given for broad-band antennas operating near 2.0 GHz and dual-frequency antennas operating at 0.9 GHz/1.5 GHz and 0.9 GHz/1.8 GHz bands.

II. Antenna Configuration

Fig. 1 is a schematic drawing of antennas comprised of two series-fed printed strip dipoles. Two printed strip dipoles of different lengths, with the arms printed on opposite sides of an electrically thin dielectric substrate, are connected through a parallel stripline. The parallel stripline consists of two broadside-coupled strips of width w_p, which is characterized by a characteristic impedance Z_0 and effective relative permittivity ε_{eff}. The antennas are fed from a conventional coaxial connector through a microstrip-to-parallel stripline tapered transition. Depending on where the antenna is fed and the way the dipoles are connected, an antenna with broad-band or dual-band capability can be designed. The double-sided configuration has been selected because it offers several practical advantages such as when required the line polarity between the strip dipoles can be easily reversed [see Fig. 1(b)], also parallel striplines offer low as well as large values of line impedances with practically reasonable conductor widths.

By feeding the antenna at the terminals of the longer element and using a direct connection between the strip dipoles, as shown in Fig. 1(a), a design with broad-band characteristics can be obtained. The direct connection between the radiating elements used in this structure gives the phase progression for endfire radiation. Because of the endfire radiation characteristic, the antenna maintains its broad-band capability when placed perpendicular to a plane or shaped ground conductor [13]. This configuration can be used when the antenna is required to provide a good impedance match over a wide frequency range.

The antenna shown in Fig. 1(b) is fed at the terminals of the shorter element and the line polarity between the dipoles is reversed. This configuration can be designed to operate at two frequency bands that are relatively far apart. The need for antennas with this capability comes from the development of wireless communication systems operating in different frequency bands [14]. For example, cellular systems working at two different frequency bands are being used in Japan (0.9 and 1.5 GHz bands), in Europe (0.9 and 1.8 GHz bands), and in the United States (0.9 GHz and 1.9 GHz bands. Since base-station antennas of different mobile systems are often installed on the same building or tower, a dual-frequency antenna that can be used by two different radio mobile systems would be space and cost efficient.

III. Broad–Band Antennas

A broad-band design can be achieved by making the longer and shorter dipoles to resonate slightly below and above the nominal center frequency, respectively, and using the direct connection as shown in Fig. 1(a). The bandwidth is maximized by successively increasing the difference between the dipole lengths and selecting an optimal distance between them [9]. The antenna generally operates as an ordinary endfire array of two dipoles. The wave propagating in the connecting line is slowed by the presence of the dielectric substrate, which increases the antenna directivity and helps to keep the maximum radiation in the endfire direction over a wide frequency range. The characteristic impedance of the connecting line also effects the overall performance of the antenna, including input impedance.

As a design example, an antenna printed on a dielectric substrate of height $h = 0.8$ mm and relative permittivity $\varepsilon_r = 2.2$ is optimized to have a maximum impedance bandwidth at around 2.0 GHz by choosing $w_1 = w_2 = 4$ mm, $L_1 = 61$ mm, $L_2 = 73$ mm, and $d = 30$ mm. The connecting line is realized in the form of a parallel stripline of width $w_p = 0.9$ mm, with the resulting calculated input impedance of this broad-band antenna shown in Fig. 2. The characteristic impedance and effective permittivity of this parallel stripline are calculated as $Z_0 = 118\ \Omega$

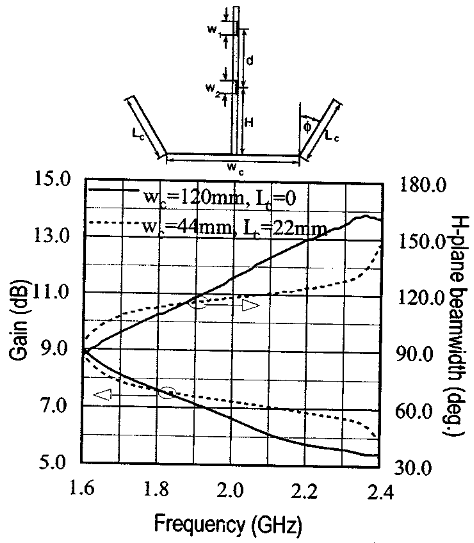

Fig. 4. Calculated gain and H-plane beamwidth of reflector backed broad-band antennas.

and $\varepsilon_{\rm eff} = 1.83$, respectively. The dimensions of this design are optimized for an antenna placed perpendicular to a plane ground reflector (see the inset of Fig. 4 with $L_c = 0$). However, because of the endfire radiation behavior, the antenna shows broad-band characteristics with or without the reflector, as can be seen from Fig. 2 where the impedance locus of the reflector-backed antenna is also plotted.

An antenna with the above stated dimensions was fabricated and its performance experimentally tested. The antenna is fed from a 50-Ω coaxial connector through a transition that gradually changes its profile from a microstrip line to a parallel stripline. The calculated and measured input return loss and gain of this antenna without ground plane are shown in Fig. 3. The antenna is well matched and has a gain of 4.5–5.5 dB over more than 30% bandwidth.

Sector beam base-station antennas with broad-band characteristics can be achieved by using the two series-fed printed strip dipoles as the radiating element above a plane or shaped reflector, as shown in the inset of Fig. 4. At lower frequencies, the radiated power contributed by the longer dipole, which is closer to the ground plane, is higher than that of the shorter dipole. As the frequency increases, the radiated power contributed by the longer dipole decreases and that of the shorter dipole increases. As a result, a design with a broad-band impedance match can be obtained but with a large variation in the radiation characteristics over the operating frequency range.

By using shaped reflectors the shorter strip dipole becomes closer to the reflector and sector zone broad-band antennas with various H-plane half-power beamwidths and small variations in the radiation characteristics can be obtained [13]. Results for the antennas placed above a planar and a shaped reflector suitable for three sector zone use are presented. In both cases, the antenna of two series-fed printed strip dipoles of the previous example is used as the radiating element placed at height $H = 30$ mm above the reflector. The planar and shaped reflector are both are 300 mm long, with dimensions $w_c = 120$ mm, $L_c = 0$, and $w_c = 44$ mm, $L_c = 22$ mm, $\phi = 30°$, respectively. In

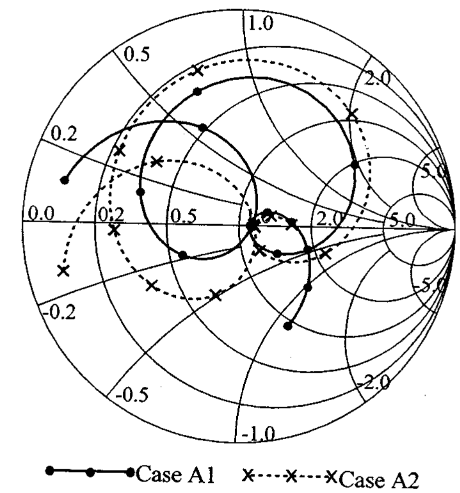

Fig. 5. Impedance loci of dual-band antennas for operation at 0.9 GHz/1.5 GHz and 0.9 GHz/1.8 GHz ($f = 0.7$–2.0 GHz).

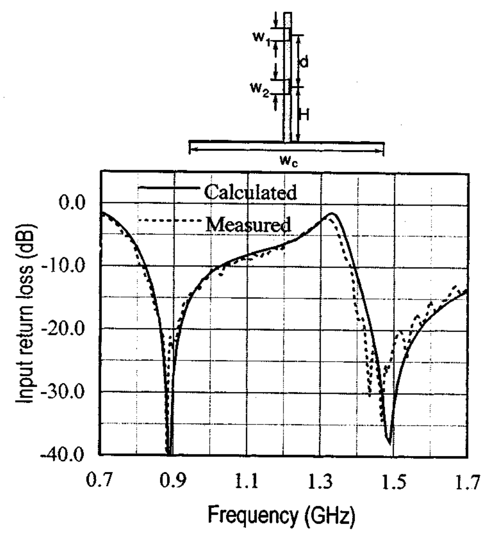

Fig. 6. Measured and calculated input return loss of the dual-frequency antenna with 120° H-plane half-power beamwidth.

Fig. 4, the calculated gain and H-plane half-power beamwidth are shown as a function of frequency. As can be seen, in comparison to the planar reflector, the shaped reflector antenna shows less variation in gain and half-power beamwidth. The measured impedance bandwidths for both antennas were found to be over 30% for $VSWR \leq 1.5$.

IV. Dual-Frequency Antennas

Our objective is to design an antenna with the far field radiated mainly from the longer element in the lower frequency band $f_1(\lambda_1)$ and that from the shorter element in the higher frequency band $f_2(\lambda_2)$. In practical applications such as in sector zone antennas used in base stations of cellular systems, a ground plane placed about $\lambda_1/4$ from the longer element and about $\lambda_2/4$ from the shorter element is used to obtain unidirectional patterns. In such cases, the distance between the radiating elements d is restricted to about 0.2_2–$0.3\lambda_2$. In order to obtain optimal antenna parameters including the above restriction on d, it has been

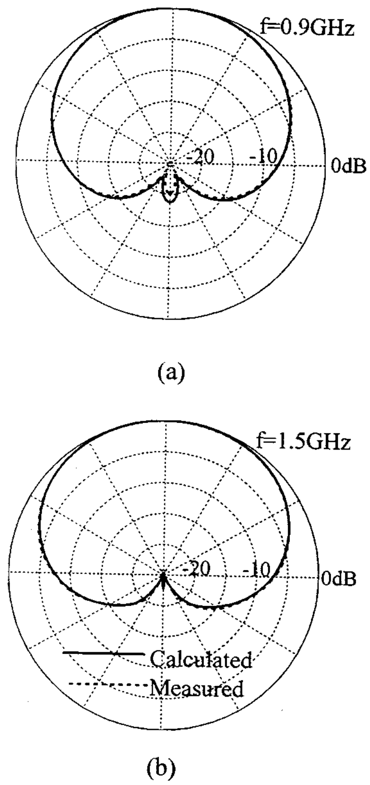

Fig. 7. Measured and calculated H-plane radiation patterns at 900 and 1500 MHz.

found that the line polarity between the radiating elements must be inverted [10]. Although this antenna has been employed in practice [1] its theoretical analysis has not been explained in detail primarily due to the presence of the dielectric inhomogeneity. As noted in the introduction, the purpose of using a printed configuration is to obtain a low-cost and low-weight antenna. However, it is found that the presence of the dielectric substrate enables a practical radiator design that has, approximately, the characteristics of two individual strip dipoles each operating in a different frequency band. Unwanted resonances on the connecting line can be excited due to the reflections from the open circuit termination. In an antenna without a dielectric substrate and separation d restricted to 0.2_2–$0.3\lambda_2$, a line resonance would be exited inside or close to the higher frequency band of operation. With a dielectric substrate present, the electrical length of the connecting line is increased and the unwanted line resonance moved somewhere between the two operating frequency bands. This enables this structure to effectively operate as a dual-band antenna, although antenna design is by the presence of the dielectric inhomogeneity.

By observing the influence of various parameters on the antenna characteristics, we have found that there is no single design parameter that impacts only one of the frequency bands. For example, the length of the longer element and the characteristic impedance of the connecting line strongly influence the antenna characteristics at the lower frequency band, but have little impact on the higher frequency band. The reverse is true for the length of the shorter element and the distance between the two elements. The antenna can be designed using the analyses techniques mentioned in the Introduction to guide fabrication, thereby reducing experimental cut-and-try design cycles.

Two dual-band antennas operating near 0.9 GHz/1.5 GHz (case *A1*) and 0.9 GHz/1.8 GHz (case *A2*) have been designed using a dielectric substrate of height 1.6 mm and relative permittivity $\varepsilon_r = 3.2$. The dipoles of the same widths $w_1 = w_2 = 6$ mm have been used. Optimal designs have been obtained by choosing $L_1 = 135$ mm, $L_2 = 78$ mm, $d = 50$ mm, and $Z_0 = 61\ \Omega$ for case *A1* and $_1 = 135$ mm, $L_2 = 64$ mm, $d = 40$ mm, and $Z_0 = 64\ \Omega$ for case *A2*. Fig. 5 shows the calculated impedance loci of these antennas in the frequency range 0.7–2.0 GHz. Dots and crosses are shown at frequency steps of 0.1 GHz. In case *A1*, the impedance curve crosses the real axis at about 55 Ω near the design frequencies 0.9 and 1.5 GHz. In case *A2*, the resonant resistance is about 58 Ω near the design frequencies 0.9 and 1.8 GHz.

An experimental antenna placed above a ground plane (see the inset of Fig. 6) has been designed for three sector zone use. The antenna is required to have the same H-plane half-power beamwidth of 120° at two design frequencies 0.9 and 1.5 GHz. For the dielectric substrate of $h = 1.6$ mm and $\varepsilon_r = 3.2$, an optimal design is obtained by selecting $L_1 = 130$ mm, $L_2 = 70$ mm, $w_1 = w_2 = 6$ mm, $d = 50$ mm, $w_p = 3.5$ mm, $H = 45$ mm, $w_c = 240$ mm. The antenna was fabricated, tested, and compared with calculated results. In Fig. 6, the calculated values of input return loss of this antenna are compared with experimental data, showing good agreement. The antenna is fed from a 50-Ω coaxial connector through a microstrip-to-parallel stripline transition, which is also used to transform the 57-Ω impedance seen at the antenna terminals. The calculated and measured H-plane radiation patterns at 0.9 and 1.5 are plotted in Fig. 7, showing almost the same beamwidth at both frequencies. The agreement between calculated and measured patterns is excellent.

V. Vertically Stacked Arrays of Two Series-Fed Printed Strip Dipoles

To narrow the antenna beam in the vertical plane and increase the power gain, a number of series-fed printed strip dipole pairs can be vertically stacked as shown in Fig. 8. Amplitude and phase distributions over the array can be controlled to obtain the desired radiation pattern. Fig. 8 shows an array example of dipole-pairs, with and the feeding arrangement for, uniform power distribution for broad-band operating characteristics. If a ground reflector is used, the feed network (that includes microstrip-to-parallel stripline transitions) can be conveniently placed in the space between the radiating elements and the reflector. The microstrip-to-parallel stripline transitions are also used as impedance transformers and are followed by a corporate network of parallel striplines. In this example the broad-band antenna above the plane reflector described in Section III is used with the element spacing of $D = 120$ mm. The experimentally measured and calculated return loss and gain of this array are shown in Fig. 9. The array showed a good impedance match over a wide frequency range. The calculated gain is found to be about 0.5 dB higher than the measured gain,

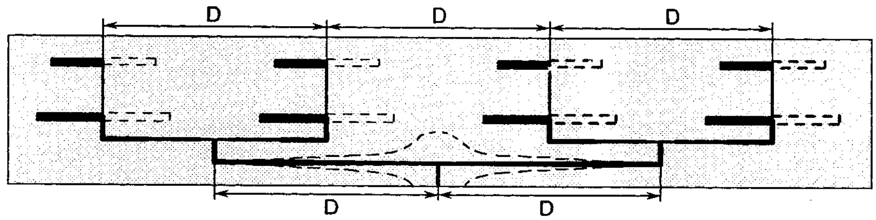

Fig. 8. Configuration of a vertically stacked array of printed-strip dipoles with a corporate feed network of parallel striplines and tapered line transitions.

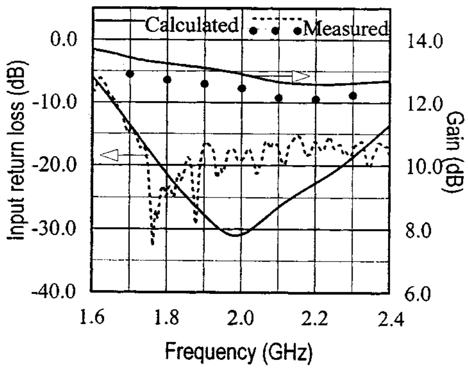

Fig. 9. Measured and calculated input return loss of the array antenna of Fig. 8.

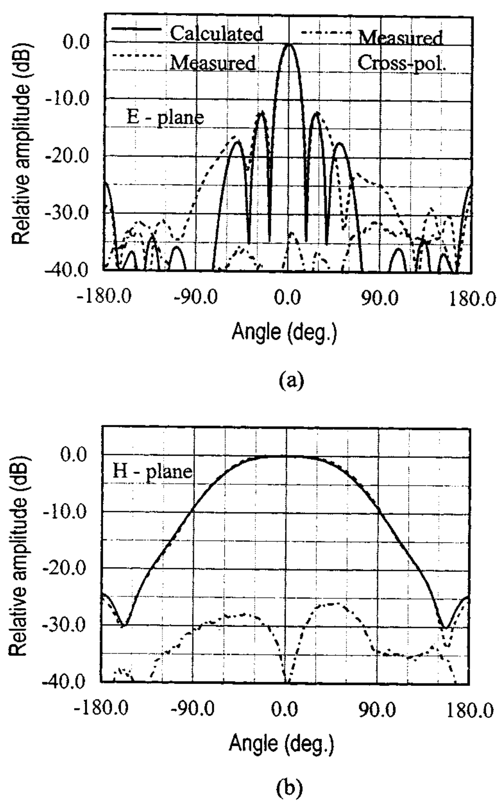

Fig. 10. Copolarization and cross-polarization patterns of the array antenna of Fig. 8 at 2.0 GHz.

which is roughly equal to the total loss of the feed network. Fig. 10 shows the E-plane and H-plane radiation patterns of this array at $f = 2.0$ GHz showing good agreement and low cross-polarization levels in both planes.

VI. Conclusion

The design of antennas consisting of series-fed printed strip dipole pairs was presented. A moment method in the spectral domain and an approximate model using equivalent circular conductors coated with dielectric or magnetic covers were used to help design the antennas. Several examples of antennas with broad-band and dual-band characteristics were shown. Antennas comprised of series-fed printed-strip dipole pairs appear well suited for use in base stations of wireless communication systems.

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