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Abstract—**A microstrip antenna with large bandwidth is developed using a parasitic technique. Compared to the available wide-band antennas, the proposed antenna structure is very compact and gives a less distorted radiation pattern with frequency. An impedance bandwidth, eight times that of a conventional patch antenna of the same size, is achieved. The concept of coupled microstrip line model is extended for theoretical interpretation of the impedance loci.**

I. Introduction

Recently, the use of microstrip antennas has become increasingly popular because of various inherent advantages such as light weight, simplicity of fabrication, ease of mass production, etc. The main handicap of microstrip antennas is their very narrow impedance bandwidth [1]. A number of papers have appeared in technical literature on bandwidth enhancement of microstrip antennas using additional resonators coupled to the driven element [2]–[4]. However, these antennas create two main problems for the designer: 1) when the parasitic elements are coupled to the patch antenna the size of the structure becomes very large, making them unsuitable as array elements; 2) the radiation pattern is highly dependent on the frequency. That is, the pattern maxima squint with frequency. A compact antenna configuration with enhanced impedance bandwidth and less distorted radiation pattern has been reported [5]. In this paper, the experimental and theoretical impedance characteristic of a patch antenna loaded with parasitic elements is analyzed in detail. The theoretical model presented here agrees with the observation excellently.

The normal rectangular patch antenna is shown in Fig. 1. The feed point is at P and the antenna is excited in the $(1, 0)$ mode. In the proposed configuration, the same patch is divided into several parts. The central section alone is fed and the remaining parts are kept as parasitics. Since the resonant frequency is also a function of width, the sections are made of unequal widths. So the different patches are resonating at different frequencies and this multiple resonance is responsible for the increase in bandwidth.

II. Experimental Procedure and Results

A rectangular patch of 90 × 10 mm was formed on a 0.8-mm thick RT Duroid substrate ($\epsilon = 2.2$). This is fed along the nonradiating edge at a distance of 40 mm from the radiating edge to obtain a 50-Ω match. The measured resonant frequency using HP-8754A Network analyzer is 1151 MHz. When another patch of 90 × 10 mm was gap coupled to the nonradiating edge, the system gives two resonances which are shifted to the low impedance side of the Smith chart. The feed point is now shifted toward the radiating edge to increase the impedance.

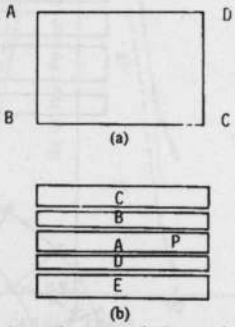

Fig. 1. (a) Rectangular patch antenna. (b) Proposed configuration. A is the driven element; B, C, D and E are parasitics.

When additional patches of widths 10, 5, and 15 mm were added to the system the feed point was shifted further toward the radiating edge. The resultant configuration is shown in Fig. 2(a). From Fig. 2(b) it can be seen that the antenna has a VSWR less than two in the frequency range of 1123 to 1175 MHz which corresponds to a bandwidth of 5%.

The overall width of the antenna (total width of strips and gaps) is 85 mm. For a comparison, a patch of 90 × 85 mm was fabricated and its characteristics were studied. This antenna has a resonance frequency of 1132 MHz and a 2 : 1 VSWR bandwidth of 0.6%. This proves that the newly designed antenna gives a bandwidth eight times that of a corresponding planar antenna.

The radiation patterns of the antenna at three different frequencies in the band of interest are given in Fig. 3. The radiation pattern measurement was conducted in a tapered anechoic chamber. It can be seen that the tilt from on-axis is very small.

III. Theoretical Analysis

The impedance characteristics of the rectangular patch antenna coupled with parasitics is analyzed by extending the theory of coupled microstrip lines [6], [7]. In this paper, the theoretical results for a patch coupled with a single parasitic element is presented.

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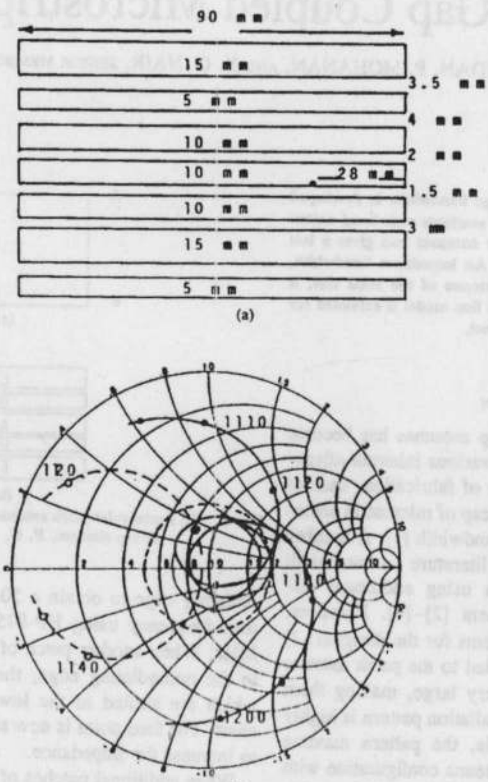

Fig. 2. (a) Parasitic coupled patch antenna. (b) Impedance loci. Solid line—parasitic antenna; Dotted line—rectangular patch antenna (90 × 85 mm).

A rectangular patch excited in the (1, 0) mode and coupled with a parasitic element along the nonradiating edge is shown in Fig. 4 (a). The distribution of capacitance of the microstrip line geometry is shown in Fig. 4 (b) and (c).

The even-mode capacitance can be divided into three as

$$C_{even} = C_p + C_f + C'_f \quad (1)$$

where $C_p = \epsilon_0 \epsilon_r (w/h)$ is the parallel plate capacitance between the strip and the ground plane.

The fringe capacitance

$$C_f = \tfrac{1}{2}\left[\sqrt{\epsilon_{eff}}/cZ_c - C_p\right] \quad (2)$$

where Z_c is the characteristic impedance of the line and ϵ_{eff} is the effective dielectric constant of the substrate.

The modification of the fringe capacitance of a single line due to the presence of another line is given by

$$C'_f = C_f\left[1 + A(h/s)\tanh(10s/h)\right]^{-1}(\epsilon_r/\epsilon_{eff})^{1/2}. \quad (3)$$

This capacitance is now modified as

$$C'_f = C_f\left[s(1 + A(h/s)\tanh(10s/h)\right]^{-1}(\epsilon_r/\epsilon_{eff})^{1/2} \quad (4)$$

where

$$A = \exp(-0.1\exp(2.33 - 2.53w/h)). \quad (5)$$

The modified C_f will decrease the ϵ^e, the effective dielectric constant for the even mode and predicts the lower resonant frequency accurately.

The odd-mode capacitance:

$$C_0 = C_p + C_f + C_{gd} + C_{ga}. \quad (6)$$

The gap capacitance:

$$C_{ga} = \tfrac{1}{2}K(k')\epsilon_0/[K(k)] \quad (7)$$

where

$$k = s/h[s/h + 2w/h]^{-1}, \quad \text{and} \quad k' = 1 - k^2 \quad (8)$$

and $K(k)$ and $K(k')$ are elliptic functions.

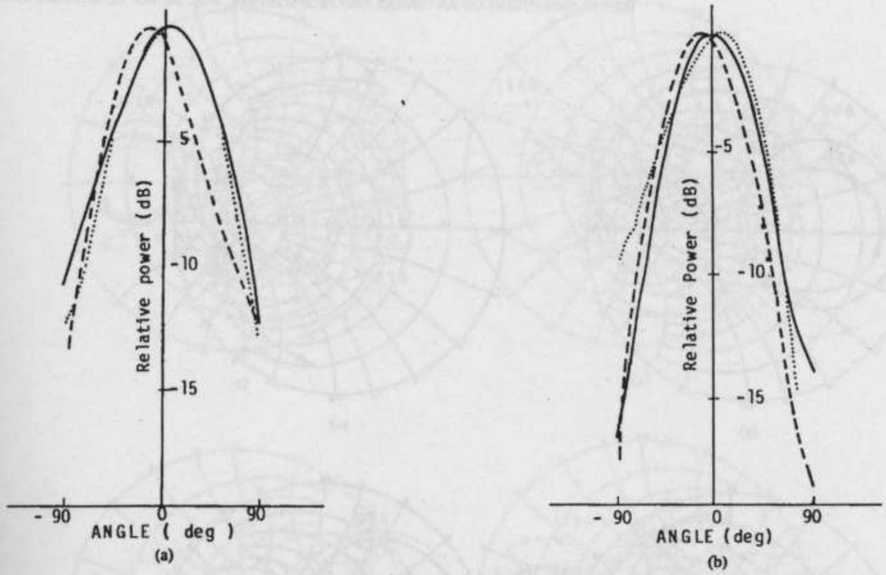

Fig. 3. Radiation patterns of the antenna configuration shown in Fig. 2(a). (a) *H*-plane, (b) *E*-plane. Solid line—1130 MHz; dashed line—1145 MHz; dotted line—1165 MHz.

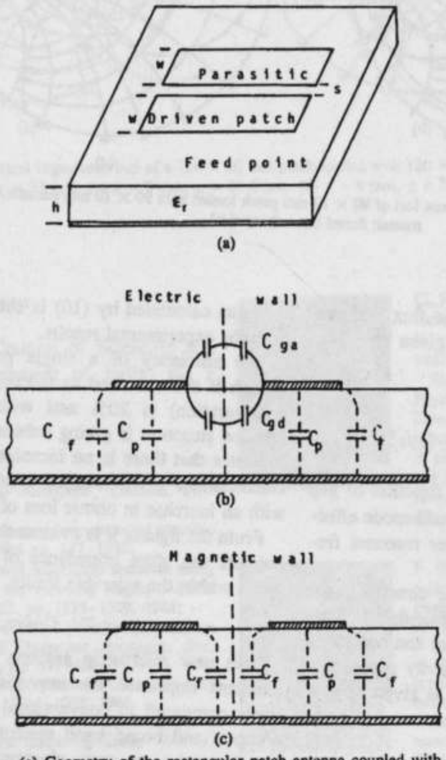

Fig. 4. (a) Geometry of the rectangular patch antenna coupled with parasitic element. (b) Even mode. (c) Odd mode capacitance of the coupled microstrip line geometry.

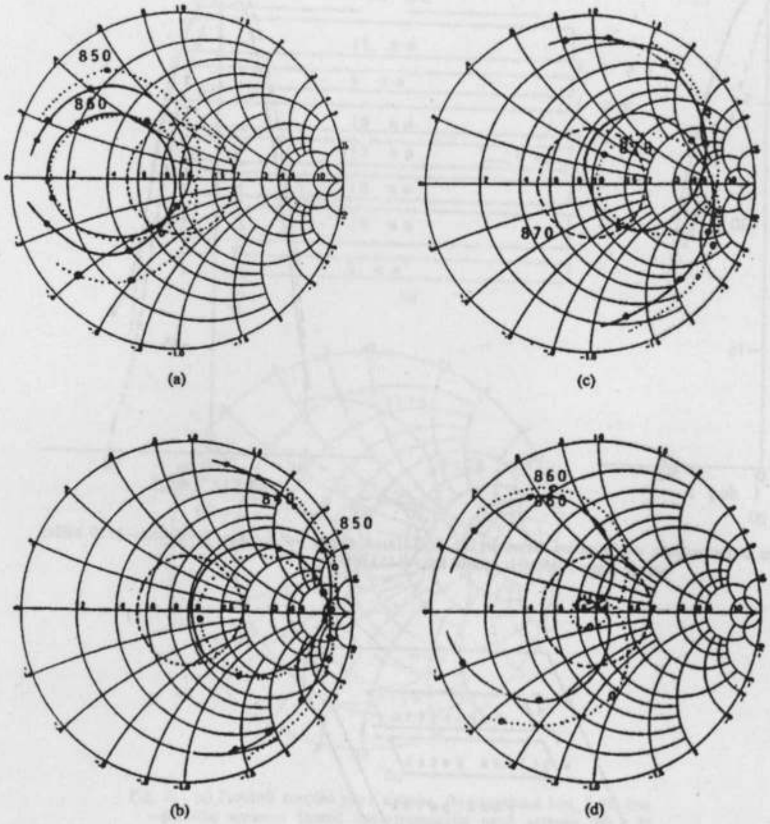

Fig. 5. Experimental and theoretical impedance loci of 90 × 10 mm patch loaded with 90 × 10 mm parasite. Solid line—experimental; dotted line—theoretical.

The capacitance formed due to the electric flux between the air dielectric region between the strips is given by

$$C_{gd} = \epsilon_0 \epsilon_r / \pi \ln\left[\coth\left(\pi s/4h\right)\right] + 0.65 C_f\left[0.02/(s/h)\sqrt{\epsilon_r} + 1 - (1/\epsilon_r^2)\right]. \quad (9)$$

In this the constant 0.65 is replaced by a function of gap width as $(0.6 - s/2)$ which modified ϵ^0 the odd-mode effective dielectric constant and predicts the lower resonant frequency accurately.

Using the even- and odd-mode dielectric constants, the upper and lower resonant frequencies are calculated. Now the input impedances for the even mode $Z_{in}(e)$ and odd mode $Z_{in}(o)$ are calculated separately using the cavity model [1]. The resultant input impedance of the system is given by

$$Z_{in} = Z_{in}(e) + Z_{in}(o). \quad (10)$$

The input impedance of a parasitic loaded microstrip antenna as calculated by (10) is shown in Figs. 5 and 6 along with the experimental results.

The efficiency of a single patch of size 90 × 10 mm (which is the one used as the driven element in the present configuration) is 20% and with respect to this, the gap coupled structure is giving enhanced efficiency of 55%. This indicates that there is no increase in ohmic loss. Hence, the enhancement of impedance bandwidth is not accompanied with an increase in ohmic loss of the system.

From the figures it is evident that the theory presented here predicts the input impedance of the present microstrip antenna within the tolerable limits.

IV. Conclusion

This new microstrip antenna gap coupled with parasitic elements improved the impedance bandwidth nearly eight times compared to conventional single patch antenna. This compact and broad band microstrip antenna can be conveniently used as an array element in phased array radars and monopulse antennas where large bandwidth is required.

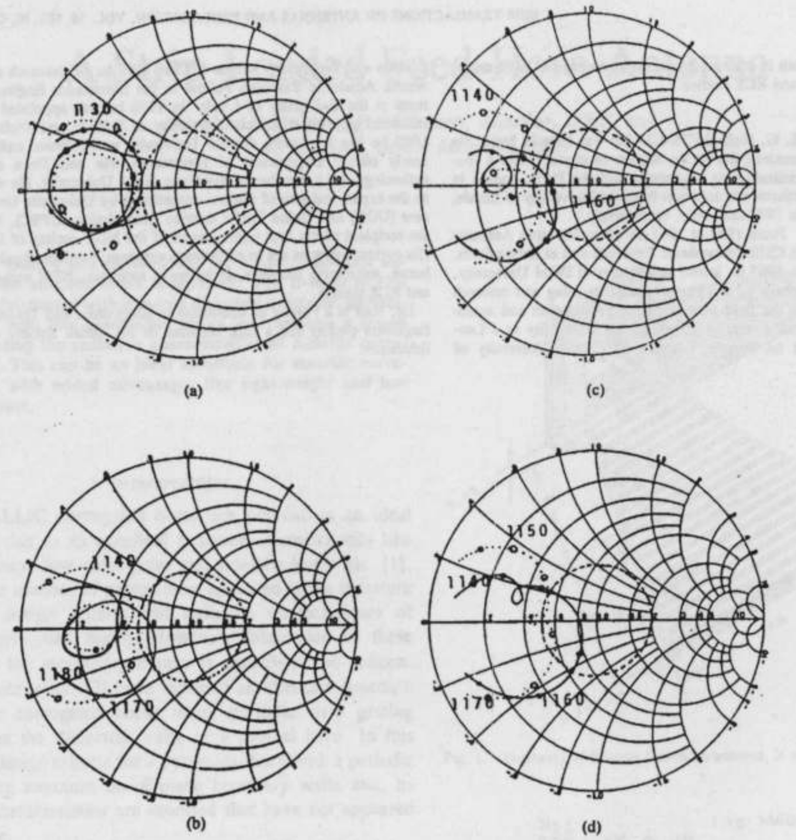

Fig. 6. Experimental and theoretical impedance loci of a 120 × 10 mm patch loaded with 120 × 10 mm parasite. (a) s = 1 mm, z = 50.5 mm. (b) s = 1 mm, z = 23 mm. (c) s = 2 mm, z = 32.5 mm. (d) s = 9 mm, z = 50 mm. Solid line—experimental; dotted line—theoretical.

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