Novel Active Antenna Amplifying Arrays

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Abstract

This paper presents a novel idea that the power is fed from the patch antenna coupler to form a five-element Chebyshev active antenna FET amplifying linear array. An equivalent lumped element circuit was developed to model the mutual coupling having good agreement with experiments. The power level coupled to the transmission line can be controlled by adjusting the length and the gap of the transmission line. The active patch-fed antenna coupler array has the advantages of a single input port, no power divider required, good and controllable radiation patterns, ease of bias, and compactness.

I. Introduction

Although the patch has gained in popularity since 1970s, the improvement of its inherent narrow bandwidth has been a very active area for research. Parasitic element(s) (open ends on both sides of the transmission line) as shown in Figure 1 coupled to the non-radiating edge of a patch antenna was used to improve the match to 50 Ω line and to increase the patch's impedance bandwidth [1]-[4]. Later, the coupled parasitic element (one end open but the other end used as a connecting port) was used as a feedback network to integrate an FET oscillator with the patch antenna [5]-[6].

The radiation patterns of a patch could deteriorate when there is a coupling. Also, active integrated antennas have shown a deterioration of both the antenna and component performance, which leads to several trade-offs in performance. If an integrated antenna can maintain component specifications with little degradation in the radiation characteristics, the approach would be very attractive for applications.

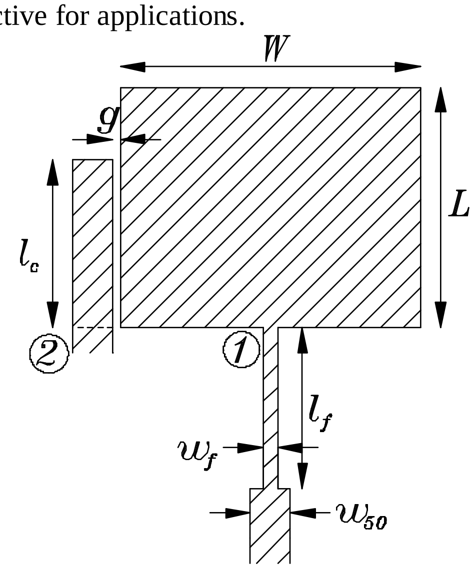

Figure 1 Geometry of a patch-fed antenna coupler.

II. Patch-Fed Antenna Coupler Design

This research starts from the study of the coupling energy between the patch and the coupled transmission line. A transmission line model was developed to represent the circuit [7]. An equivalent lumped-element circuit shown in Figure 2 was then derived from asymmetric coupled transmission lines to model the weak magnetic energy coupling (mutual capacitive coupling being ignored). The results reveal that the operating frequency and radiation patterns were only slightly affected from the coupled transmission line. Different levels of coupling energy could be controlled by adjusting the length and the gap of the transmission line. Since the coupling between patch and the coupled transmission line is weak, if two coupled transmission lines are placed on both sides of the patch, almost equal amounts of the energy are coupled to both lines because of current distribution being an even function on radiating edges.

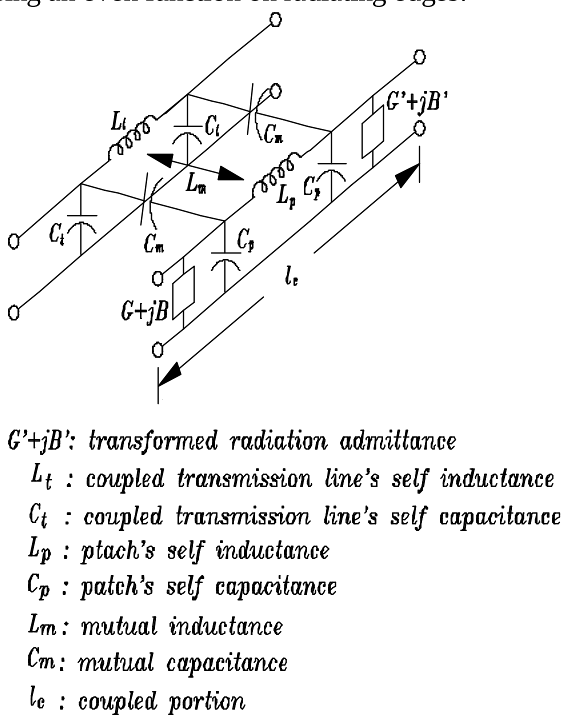

Figure 2 Equivalent lumped element circuit of the coupled portion of the patch-fed antenna coupler.

The patch design was first calculated using the Transmission Line Model equations and then simulated using PCAAD [8]. EM simulator IE3D [9] was finally used to simulate the antenna coupler. The circuit was printed on a 20-mil RT/Duroid 5880 substrate. The radiating edge (*W*) was found to be 12 mm to avoid higher order modes [10]. The half-wave resonant edge (*L*) is 9.594 mm. The resonant input resistance is 164 Ω. The quarter-wave transformer to the 50 Ω line was found to be 0.562 mm wide and 6.406 mm long. The gap and length variations were simulated by fixing either g = 0.3 mm or l_c = 0.7 L. The gap variations have stronger influence on operating frequency. The coupling results as a function of normalized coupled line length are shown in Figure 3. The operating frequency was shifted to 9.9 GHz. The theoretical results agree very well with measurements.

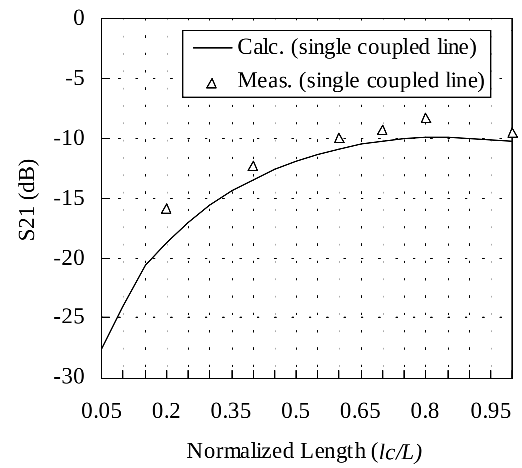

Figure 3 (a) Amplitude of coupling as a function of normalized coupled line length
with gap g=0.3 mm.

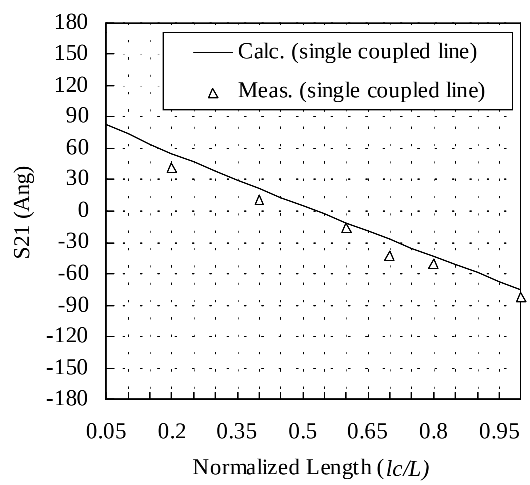

Figure 3 (b) Phase of coupling as a function of normalized coupled line length with gap g=0.3 mm.

III. Active Patch-Fed Transmitting Amplifying Array Using FET Amplifiers

For a transmitting antenna, a high gain amplifier is required. Usually, the common-emitter or common-source configuration is chosen for highest gain [11]-[12]. A common-source configuration was selected to design the amplifier and pseudomorphic Hetero-Junction FETs (NEC model NE32484A) were used for its high gain and low noise figure characteristics. The amplifier circuit was optimized using Libra. Maximum gain

($G_{tu,\max}$) is 12.613 dB and the optimized transducer power gain is 13.831 dB. The measurement shows 11.801 dB power gain and approximately 0.5 dB gain flatness at frequencies from 9.6 to 10.4 GHz. The phase is -103.379^o at 9.9 GHz. The noise figure is -13.01 dB and the power added efficiency is 17.35 %.

By integrating the coupled transmission line with an FET amplifier, the coupled port could be fed directly to the next patch element. The gap between the patch and coupled transmission line behaves as a DC block (while biasing the FET amplifier) which simplifies the bias circuit. An active Chebyshev transmitting linear array shown in Figure 4 was designed to demonstrate the validity of the patch-fed antenna coupler. The amplitude distribution shown in Figure 5 for the reference level of microwave power to the center element is 1 mW. Based on this amplitude distribution, the coupling gaps and lengths were designed according to Figure 3.

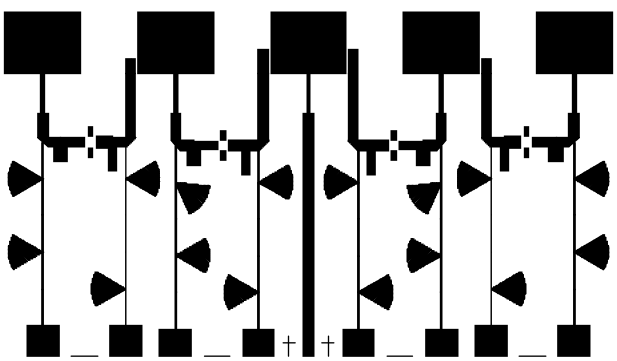

Figure 4 A five-element Chebyshev active transmitting amplifying array.

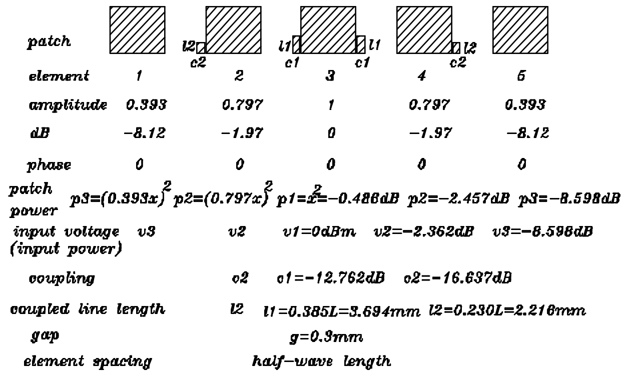

Figure 5 A five-element Chebyshev array amplitude distribution diagram and the design of coupling gaps and lengths.

Ideally, power received at broadside for both *E*- and *H*-plane power patterns should be the same. It is observed from Figure 6 that received power at broadside for both co- and cross-polarization in *E*- and *H*-plane power patterns are almost equal. The power received at broadside as shown in Figure 6 (a) is -17.57 dBm (=1.75×10^{-2} mW) and is used to calculate the *EIRP*. The half power beamwidth is 26^o. The power level for both *E*- and *H*-planes is increased after the first and second stage FET amplifiers are turned on. The *E* plane power patterns are broad and do not change the shape because they are considered as one element array. The power level increases and the beam becomes sharper in the *H*-plane power patterns since it is a five-element linear array in the *H*-plane. Both patterns are affected by the FET device having large size with respect to the antenna and therefore disturb the fields within the antenna. All FET amplifiers were biased together with the same V_{gs} =-0.2 V and V_{ds} =2 V to have the advantage of equal bias on each FET amplifier. The total current flow (I_{ds}) is 50 mA. The summation of the DC power ($\sum P_{DC}$) is 100 mW. The standard gain horn receives -12 dBm with the same RF input as the Chebyshev array. By substitution, the array's transmitting gain (G_t) is 10.59 dB. Power transmitted by the array (P_t) is 2.688 mW. The *EIRP* is 30.789 mW and *DC-to-RF* efficiency is 2.688 %. Although the power output is low, the concept has been demonstrated.

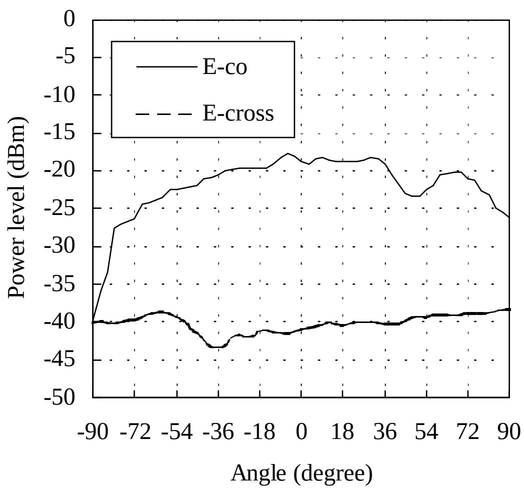

Figure 6 (a) *E*-plane power pattern of the five-element active Chebyshev amplifying array.

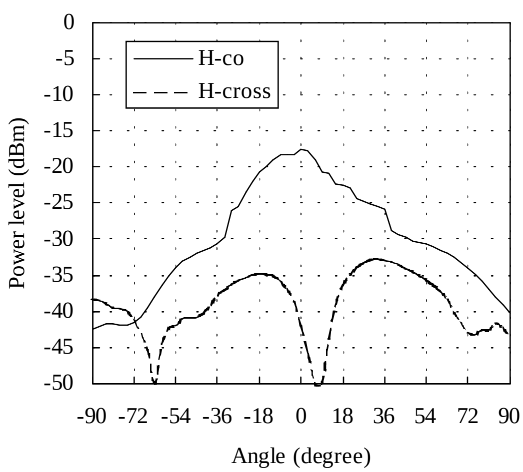

Figure 6 (b) *H*-plane power pattern of the five-element active Chebyshev amplifying array.

IV. Conclusions

The patch-fed antenna coupler is used to integrate with FET amplifiers and becomes an active antenna amplifying array having applications in power combining and active phased array. A lumped element circuit is developed to model the weak magnetic energy coupling of the patch-fed antenna coupler. The active antenna's power patterns are slightly affected by the insertion of FET amplifiers. However, the overall patterns are satisfactory. This work should have applications in communication and radar systems.

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