MSAT Vehicular Antennas with Self Scanning Array Elements

L. Shafai
Dept. of Electrical and Computer Engineering
University of Manitoba
Winnipeg, Manitoba, Canada R3T 2N2
Tel. (204) 474-9615 FAX (204) 261-4639

ABSTRACT

This paper presents a new approach for designing low profile antennas for MSAT applications. It is based on stacking two microstrip antennas that operate at two adjacent modes. The beam scanning is achieved by introducing a phase shift between the stacked elements and consequently a low cost self scan array element is developed. The concept is used to investigate two different antenna types: 1) a single element unit, with its phase shifter, that provides a moderate gain of about 7 dBic, and 2) a seven element array with a peak gain of about 14 dBic. Computed and measured data for each design are presented and discussed

BEAM SCANNING CONCEPT

Assume N-stacked circular patches, where each operates at one of TM_{n1} modes. If the radiation is circularly polarized, the components of the far field pattern can be written as

$$E^c_{\theta,\phi} = \sum_{n=1}^{N} f_n(\theta)\, e^{in\phi} \qquad (1)$$

where

$$f^\theta_n = \frac{vak_0 j^n}{2} \frac{e^{-ikr}}{r} \left[J_{n+1}(k_0 a \sin\theta) - J_{n-1}(k_0 a \sin\theta)\right] \qquad (2)$$

and

$$f^\phi_n = \frac{-vak_0 j^n}{2} \frac{e^{-ikr}}{r} \cos\theta \left[J_{n+1}(k_0 a \sin\theta) - J_{n-1}(k_0 a \sin\theta)\right] \qquad (3)$$

when the excitation of each TM_{n1} mode (i.e. each patch) has a relative phase difference of δ_n, equation (1) modifies to

$$E^c_{\theta,\phi} = \sum_{n=1}^{N} f_n(\theta)\, e^{in\phi - j\delta_n} \qquad (4)$$

and selecting $\delta_n = n\delta_1$ provides

$$E^c_{\theta,\phi} = \sum_{n=1}^{N} f_n(\theta)\, e^{in(\phi - \delta_1)} \qquad (5)$$

For equation (1) the beam peak is located in the $\phi = 0$ plane, and moves to $\phi = \delta_1$ plane for the pattern of equation (5). Now, if the phase differences of $n\delta_1$ are generated by external phase shifters, the array beam can be scanned by varying the relative phase of each stacked element. In particular, increasing the number of stacked elements reduces the beamwidth and consequently increases the array gain.

The above array formation by stacking the TM_{n1} patches also alters the radiation patterns in the θ- direction. Only the TM_{11} mode radiates axially in the $\theta = 0$ direction. All other TM_{n1} modes radiate conical beams, with a null at $\theta = 0$ direction. Consequently, the pattern peak of the stacked arrays occurs, somewhere between $\theta = 0$ and 90°, depending on the number of stacked elements and the substrate dialectric constant.

SINGLE STACKED ELEMENT

In the present study, since only two stacked microstrip patches are utilized, the operating modes are the TM_{11} and TM_{21} modes. Fig. 1 shows the geometry of the structure. Their individual radiation patterns, when each patch is over an infinite ground plane, are shown in Figs. 2 and 3. The substrate dielectric constant is $\epsilon_r = 2.52$. Consequently, the principal plane patterns are not identical, but can be made to be similar by selecting an appropriate ground plane size. For the stacked configuration the computed circularly polarized patterns, in the $\phi = 0, 180$ plane, are shown in Figs. 4a and 4b. The peak gain is 7.9 dBic, which occurs at about $\theta = 32°$, Fig. 4a, and the beamwidth in the θ-direction is about 30 degrees. The generated sidelobe is small, about -20 dB, and occurs at an angle of 70 degrees behind the main beam, $\phi = 180°$ plane. The horizontal copolar pattern, in a plane containing the beam peak, i.e. $\theta = 32°$, is shown in Fig. 4b. The beamwidth is about 180 degrees, and the pattern has no sidelobes.

An experimental unit was fabricated and tested. Fig. 5 shows the measured copolar patterns at two adjacent frequencies. The centre frequency of the patches was selected to be 3.165 GHz, to reduce the element size. The antenna ground plane was small, 4 in x 4 in, but the measured patterns still agree well with computations. The achieved peak gain of 7.56 dBic is also close to computed value of 7.9 dBic.

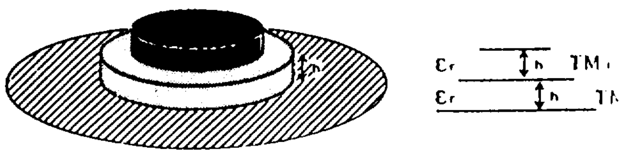
SEVEN ELEMENT ARRAY

Using the above stacked TM_{11}, TM_{21} mode element, a 7-element array was formed, that is shown in Fig. 6, and its performance, with and without mutual coupling effects was investigated. For the symmetric planes, i.e. $\phi = 0$ and $30°$, the computed results are shown in Figs. 7 and 8. Fig. 7a shows the copolar pattern with and without mutual coupling in the $\phi = 0$ plane. For the selected dimensions the effect of mutual coupling is small and does not alter the gain or the pattern shape significantly. The beam peak is at $\theta = 47°$ (elevation of 43°), where the array gain is about 13.8 dBic and reduces to 11.0 dBic at the elevation angle of 22°. Since the ground plane is selected to be an infinite one, the co- and cross-polar fields become equal at the horizontal plane. The computed patterns in the $\theta = 47°$, are shown in Fig. 7b, and for the selected beam the sidelobe levels are reasonably high.

Figs 8a and 8b show the corresponding results when the beam is scanned to $\phi_0 = = 30°$, $\theta_0 = 60°$ direction. For this beam the grating lobe of the array falls outside the real space and the array gain and sidelobes improve. The beam peak occurs at $\phi = 30°$, $\theta = 48°$ (elevation of 42°), where the array gain is increased to 14.3 dBic. The copolar patterns in the $\theta = 48°$, are shown in Fib. 8b and again have reduced sidelobe levels.

The 7-element stacked array was fabricated and tested for performance at both beams. Sample of measured results are shown in Figs. 9 and 10, respectively for ($\phi_0 = 0$, $\theta_0 = 60°$) and ($\phi_0 = 30°$, $\theta_0 = 60°$) beams. The measured peak gain of these beams, excluding circuit losses, were at 12.34 dBic and 13.80 dBic, respectively, which are somewhat below the computed values. The discrepancies are partly due to the mismatch and polarization losses, and partly due to the phase errors and finite ground plane size. The effect of phase error is evident from the beam peak, where the pattern is nearly flat between 48° and 60° range.

To scan the array beam one needs two different sets of phase shifters. Array elements require seven corse phase shifters (2 or 3 bits), since their azimuthal pattern is broad and has a 3 dB beamwidth of about 180°. For interelement phasing, six finer (4 bit) phase shifters are necessary to scan the array beam. That is in total one requires 13 phase shifters, which is five less than the number needed for a 15-element TM_{11} mode array. Both arrays have similar gains for the 20° to 60° elevation range.



Geometry of Two Stacked Microstrip Antennas

Fig. 1.

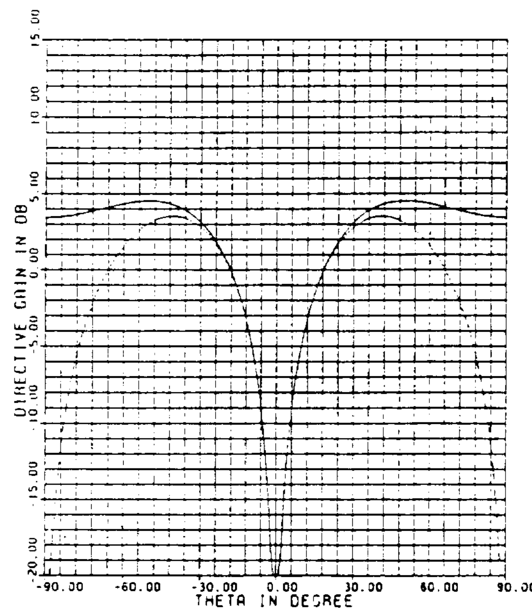


Fig. 3. E and H plane patterns for the TM_{21} mode patch,

——— E-plane, - - - H-plane

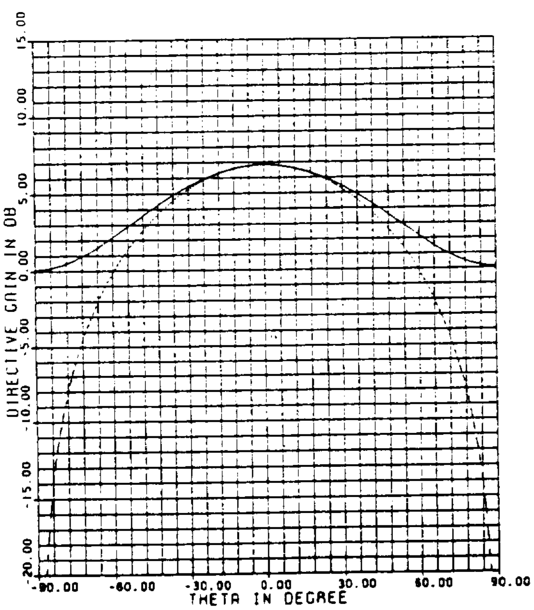


Fig. 2. E and H plane patterns of the TM_{11} mode patch over an infinite ground plane, $\epsilon_r = 2.52$

——— E-plane

- - - - H-plane

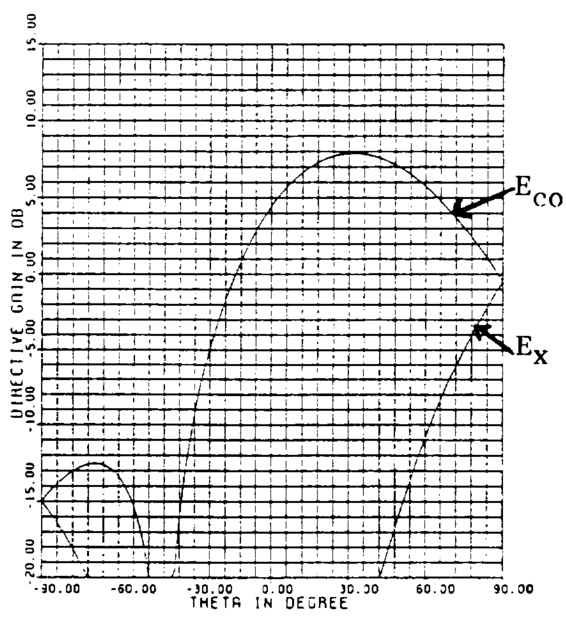


Fig. 4a. Co- and cross-polar (circular) patterns of stacked TM_{11} + TM_{21} modes.

ϕ = 0.0/180, $\epsilon_r = 2.52$

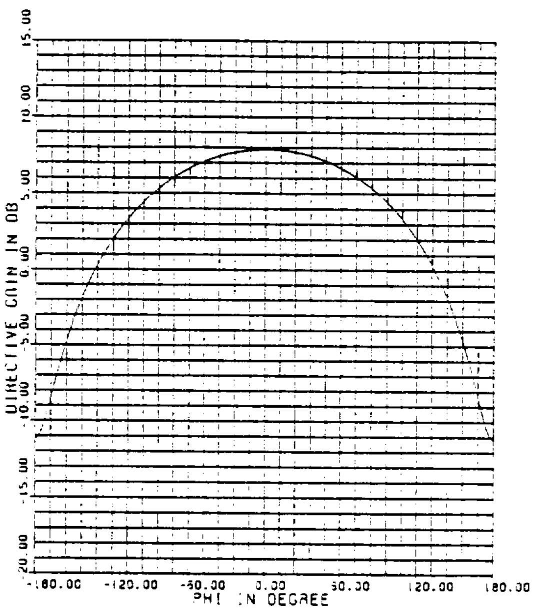


Fig. 4b. Co- and cross-polar (circular) patterns of stacked TM_{11} + TM_{21} modes.

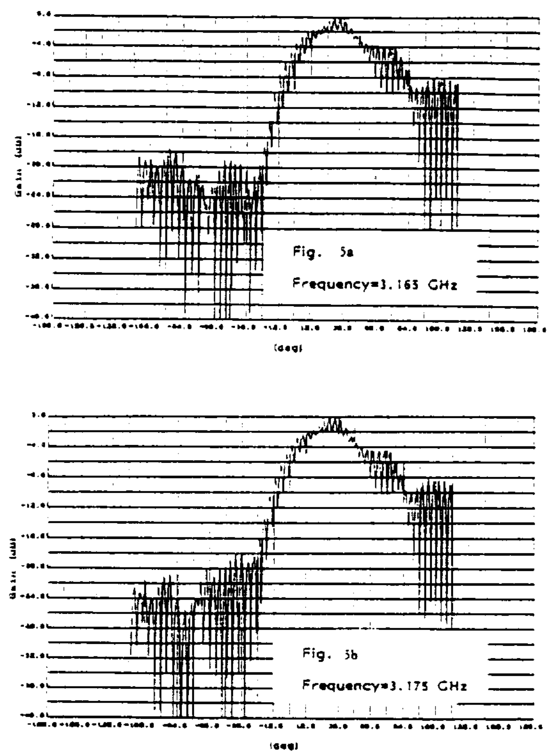


Fig. 5. Experimental patterns of stacked TM_{11} + TM_{21} modes, ϵ_r = 2.52, h = 1.6 mm, gain = 7.56 dBic

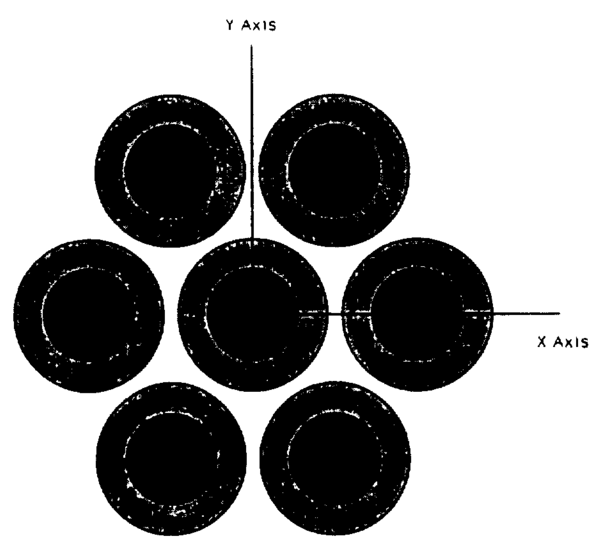


Fig. 6.

Triangular Array of Seven Dual Mode Microstrip Elements

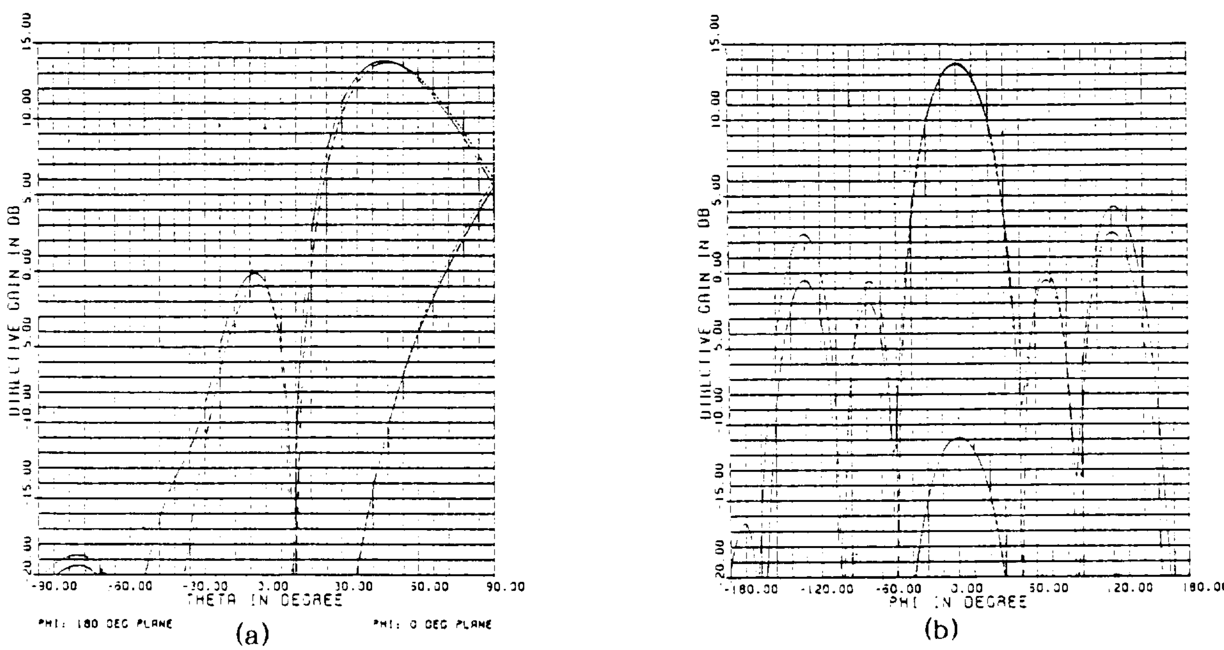


Fig. 7. Computed co-polar and cross-polar patterns of the 7-element array, $\epsilon_r = 2.52$, 0.0 degree beam ($\phi_0 = 0.0$, $\theta_0 = 60.0$)
——— without mutual coupling, - - - - - with mutual coupling

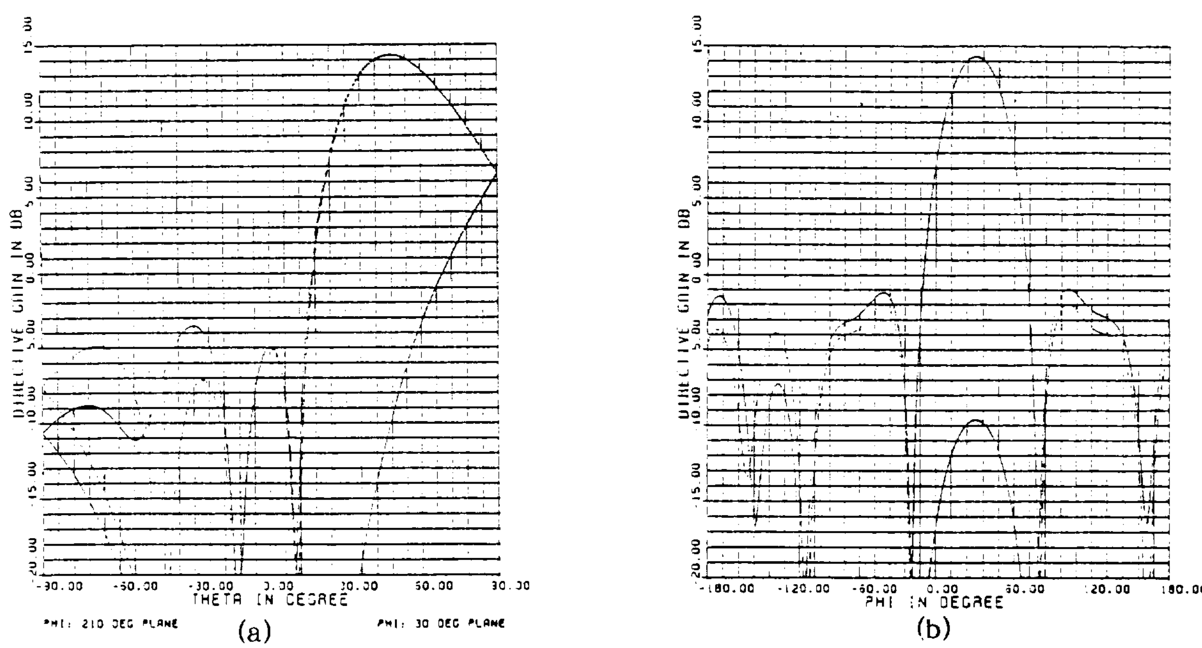


Fig. 8. Computed co-polar and cross-polar patterns of the 7-element array, $\epsilon_r = 2.52$, 30-degree beam ($\phi_0 = 30.0$, $\theta_0 = 60.$)
——— without mutual coupling, - - - - - with mutual coupling

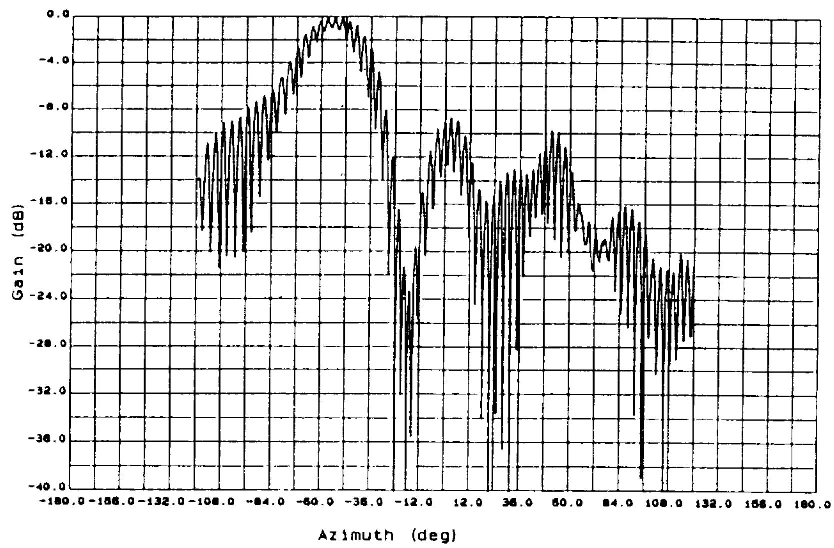


Fig. 9. (ϕ_o = 0.0, θ_o= 60.), gain = 12.34 dBic

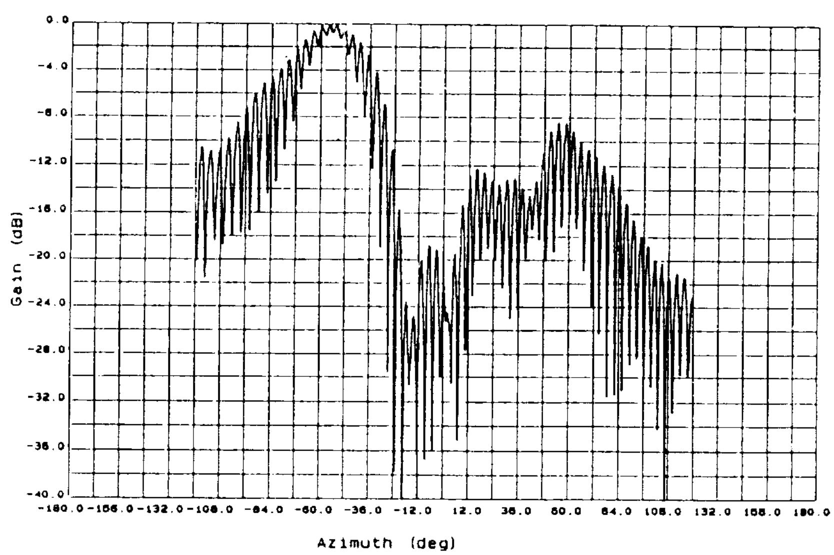


Fig. 10. (ϕ_o = 30.0, θ_o = 60.0), gain = 13.80 dBic

Fig. 9 and 10. Measured patterns of the 7-element array, ϵ_r = 2.52, f = 3.16 GH_z