LOW COST CARTOP PHASED ARRAY STEERING

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ABSTRACT

Under J.P.L. and NASA we are developing a cartop phased array antenna for MSAT auto transceivers. The beamsteering system consisting of eighteen 3 bit phase shifters and a nineteen way divider operating from 1545 to 1660 mhz is described. Criteria for material and part selection is discussed. An overall schematic for both circuits is given. The phase shifter development is illustrated with a schematic, predicted performance and measured performance. The nineteen way divider, presenting a greater challenge, is also discussed. Schematic, layout, predicted and measured performances are also given. The technology being evolved appears promising for achieving an affordable mobile communications system for rural areas.

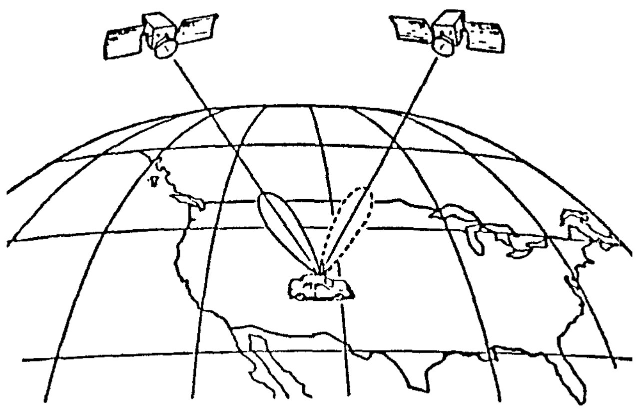
INTRODUCTION

A low cost phased array antenna system is being developed to provide mobile communications for rural areas in the 1990's via the MSAT satellite and system developed by J.P.L. under NASA direction.[1] A brief description of the MSAT system will be presented as well as the phased array antenna. Mainly, however this paper is concerned with one effort to develop low cost steering for that phased array. The work is being done by Teledyne Ryan Electronics under a J.P.L. contract. Two major circuits for the phased array system will be discussed: the eighteen 3 bit phase shifters and the one to nineteen way divider to be placed on one MIC board. The operating frequencies are 1545 - 1560 mhz for receive and 1645 - 1660 mhz for transmit. Approximately 10 watts will be transmitted. It is desired to have the beamsteering loss less than 2 db. The antenna assembly will fill about a 21 inch diameter and will have a very low profile above the car roof.

The design philosophy is to use the least expensive, low loss board material capable of operating in the difficult automotive environment with cheap pin diodes, capacitors, chokes and resistors all meeting required performance criteria. The entire design must be consistent with robotic assembly. Both the phase shifters and divider seem to meet these requirements while maintaining excellent microwave performance. A study was made of suitable board materials. We came back to .031" teflon fiberglass costing about $15/sq. foot in volume. Clearly a good low loss, low cost, yet reliable board material is needed.

MSAT SATELLITE SYSTEM

The MSAT system will allow moving vehicles to communicate throughout the continental United States as pictorially shown in Fig. 1. The uplink will operate from 1645-1660 mhz and the downlink from 1545-1560 mhz. A vehicle will track one of two satellites within line of sight from a series of satellites covering the entire continent. The two satellites allow doubling the system capacity without interfering with one another. They have opposite circular polarization to achieve isolation. The moving vehicle tracks its satellite via a phase steered tracking system.



STEERED ANTENNA BEAM, 10-12dBi GAIN

Fig. 1. Rooftop Vehicle Antenna in Multiple-Satellite Operation

THE PHASED ARRAY CONCEPT

Mounted on the vehicle roof, as shown in Fig. 2, the steerable antenna automatically searches for and locks on to the correctly polarized satellite. As the car turns the system stays locked by using a sequential lobing scanning method. The antenna system consists of a series of 19 radiating crossed slots and feeds, a beamformer made up of a nineteen way divider and 18 3 bit phaseshifters with drivers, and an electronics package consisting of a north seeking gyro, a microcomputer and a power supply.

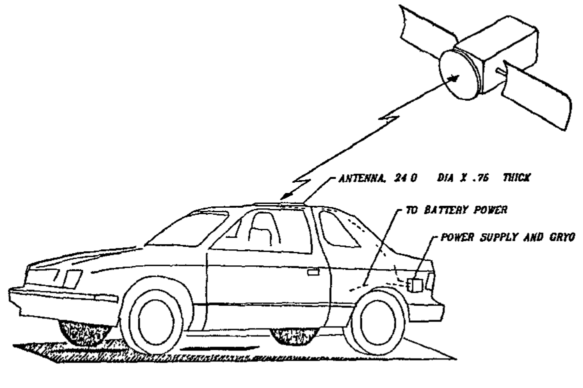


Fig. 2. MSAT Vehicle Antenna System Location

An exploded view of the antenna assembly is shown in Fig. 3. The layers include the radome, cross slots, stripline feed for the cross slots, stripline power divider circuitry, and the beamformer. The assembly makes a six layer bonded package.

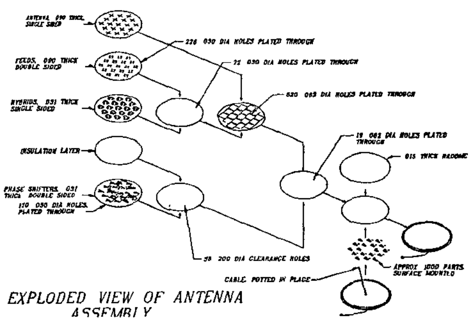


Fig. 3. Exploded View of Antenna Assembly

This array is intended for a mass market so the cost of the antenna must be low. The Jet Propulsion Lab has set a $1500 manufacturing cost goal for it. Clearly this calls for significant innovation and investment in design, materials, manufacturing techniques, and test methods. The beamformer and its cost, being probably the most labor and material intensive part of the assembly is key to achieving the $1500 goal. While the program is in its early stages selected design and fabrication methods and preliminary results should be of interest to the microwave community.

THE THREE BIT PHASE SHIFTER

The 3 bit phase shifter uses the switched line principle. This was selected to give the least phase shift error over the entire band. Performance was compared with a hybrid coupled phase shifter which did not project to be as accurate over the band. The switched line shifter projects an 11 degrees error over the band while the hybrid one projects an 19 degrees error over the band leading to the selection of the switched line approach.

The requirement is to provide two way low loss phase shifting with power handling of about 1 watt. This means a diode must be selected to have in excess of 100 volt breakdown. Since 18 phase shifters are required with 216 pin diodes, these diodes must be inexpensive. A surface mount diode Metelics MPM7484 on a ceramic carrier has been selected. This diode has low junction and case capacitances permitting series connections. The circuit is designed to have only positive voltages used on the driver. This simplifies the power supply. Predicted performance is shown in Fig. 4 for insertion loss over the band at minimum 0 deg. phase shift and maximum 315 deg. phase shift. Measured performance for an early phase shifter prototype is superimposed in Fig. 4. It can be seen the insertion loss is only a from 1 to 1.5 db in all phase shift conditions. This is an important attribute.

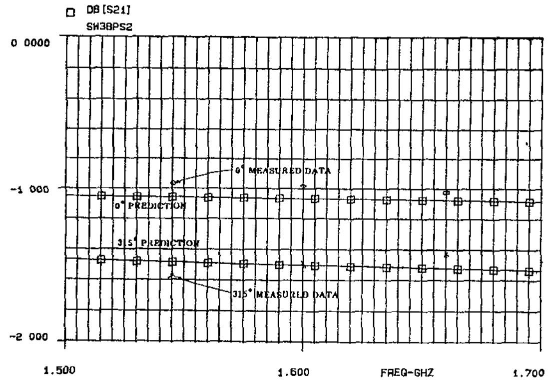


Fig. 4. Predicted and Measured Performance

The design is to use the model shown in Fig. 5 in the Touchstone Computer program for analysis and phase adjustment. The particular design chosen facilitated the beamformer layout by having most control leads on one side. Figure 6 shows a photograph of the measured phaseshifter prototype. It is made quite compact because 18 of these with drivers must fit on the beamsteering board.

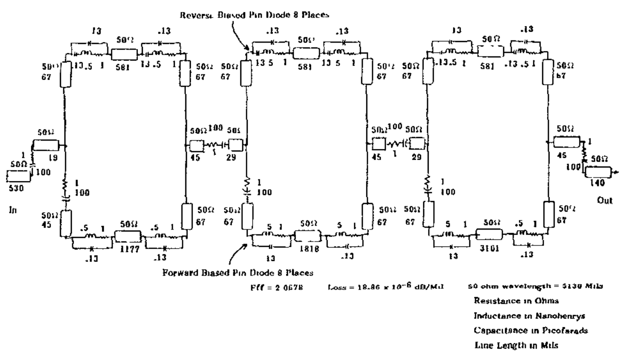


Fig. 5. Model of 3-Bit Phaseshifter Used for Touchstone Analysis

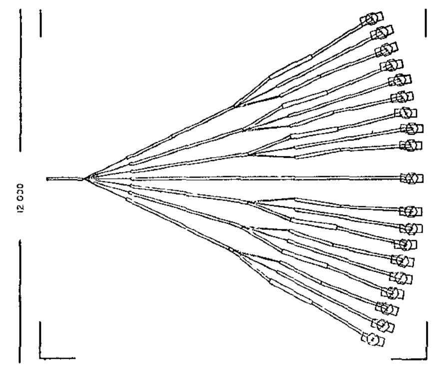


Fig. 6. Photograph of 3-Bit Phaseshifter Protype

Fig. 8. Layout of 19-Way Divider Breadboard

THE NINETEEN WAY DIVIDER

The nineteen way divider provided a somewhat greater challenge. Tapering of power for the antennas was desired for the circular geometry. Starting from the outside going towards the center three circular rings of relative power -6db, -5.2db, and -3db, respectively for each radiator compared to the 0db reference at the center are provided. To do this most effectively it was decided to use a uniform one to seven way divider followed by six unequal one to three dividers. Touchstone optimization was used in the design for line impedances and resistor values. Fig. 7 shows a schematic diagram, Fig. 8 shows a layout of the breadboard, Fig. 9 shows the predicted results and Fig. 10 shows the measured results. To achieve the results of Fig. 10 significant improvement had to be made by a different grounding scheme for the MIC board. Extra grounding had to be provided at each connector board interface. At this point we are optimizing the full scale divider circuits in preparation for building an integrated beam steering assembly. From there the beam steering assembly will be integrated with the remainder of the antenna system. Testing of the entire antenna will then commence.

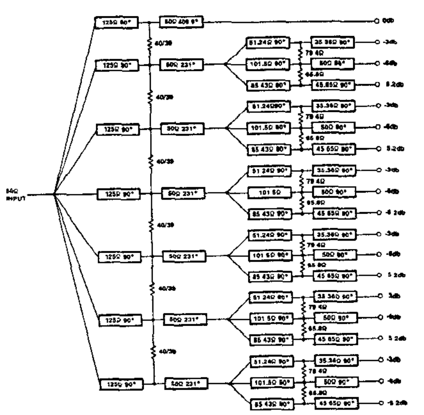


Fig. 7. Schematic Diagram of 19-Way Divider

LOSS

FREQUENCY GHZ	REF LOSS L_R DB	-3 DB LOSS L-3 DB	L-3 - L_R DB	-5.2 DB LOSS L-5.2 DB	L-5.2 - L_R DB	-6 DB LOSS L-6 DB	L-6 - L_R DB
1.545	8.667	12.049	3.382	14 280	5.613	15.065	6.398
1.600	8.633	11.864	3.231	14.091	5.458	14.879	6.246
1.660	8.655	11.768	3.113	14.001	5.346	14.785	6.13

PHASE & VSWR

FREQUENCY GHZ	TO REF. PHASE DEG	VSWR IN S11 DB	VSWR OUT S22 DB	-3 DB PORT PHASE DEG	-3 DB PORT VSWR OUT S33 DB	-5.2 DB PORT PHASE DEG	-5.2 DB PORT VSWR OUT DB	-6 DB PORT PHASE DEG	-6 DB PORT VSWR OUT DB
1.545	-121.46	-18.94	-34.62	-121.81	-12.47	-121.53	-16	-121.89	-13.76
1.600	-139.96	-24.51	-40.65	-141.1	-14.73	-141.04	-17.7	-141.05	-12.78
1.660	-160.64	-19.73	-45.73	-163.39	-19.48	-163.59	-20.75	-163.2	-11.96

Fig. 9. Theoretical Performance Characteristics of 1 to 19 Way Unequal Power Divider

-512 DB

PORT #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
IDEAL	11 63	14.63	13.83	11 63	14 03	13.83	11 63	14 63	13 83	8 63	13.83	14 63	11 63	13.83	14.63	11 63	13 83	14 63	11 63
FREQ. MHZ																			
1540	11 87	15.12	14.03	12 69	15.76	14.77	12 74	15.71	15 02	8 86	14 89	15 81	12.24	14 79	15 61	12.65	13 99	15 10	11 89
1600	11 96	15 07	13 98	12 50	15 50	14 59	12 72	15 62	14.89	8 45	14 95	15.78	12.30	14.65	15 44	12.65	14 06	15 05	12 02
1660	12.24	15.07	14.10	12.57	15.41	14.56	12.98	15 73	15 23	8 35	15 24	15.91	12 74	14 82	15 49	12 95	14 37	15.32	12 47

FREQ MHZ	S11 MAG	TOTAL LOSS -DB	-3 DBR AVE -DB	-3 DB STD DEV -DB	-5.2 DBR AVE. -DB	-5 2 STD DEV -DB	-6 DBR AVE -DB	-6 DB STD DEV. -DB
1540	257	66	12 35	40	14 58	.45	15 52	32
1600	.200	.57	12 36	.32	14 54	.43	15 41	29
1660	083	.73	12 69	29	14.72	.46	15.49	.30

Fig. 10. 19-Way Divider Performance (Wire Adjustment, No Resistors)

Figure 11 shows the order of the power divider and the 18 phase shifters. The 19th arm is the reference. All arms lead to circularly polarized antenna elements. The entire beamformer board layout is shown in Fig. 12. This board measuring over 20 inches in diameter includes all driver circuits besides the previously described power divider and phase shifter.

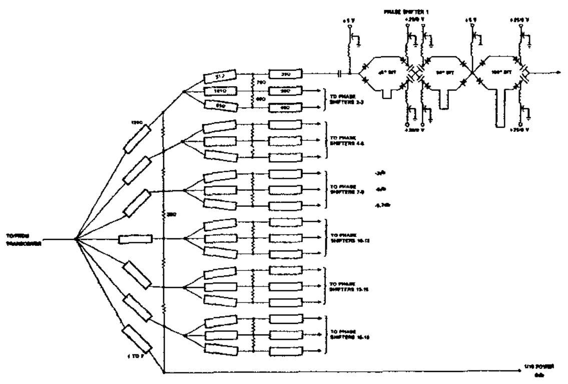


Fig. 11. Schematic Representation of Power/ Combiner and 3-Bit Phase Shifter

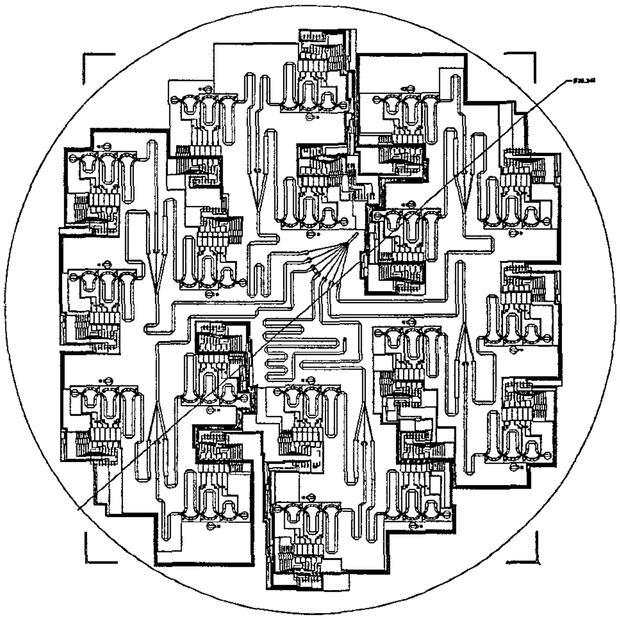


Fig. 12. Layout of the MSAT Beamformer Board

To us this technology appears very promising to provide a reasonably priced mobile communications facility for the rural United States. Much work remains, however, to fully productionize the antenna system including the fabrication, assembly, and test functions. The cost goals require the job be done right all along the production process. With robotics and automated testing we feel this requirement is feasible providing the design has a good margin.

ACKNOWLEDGEMENTS

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REFERENCES

1. Robert R. Lowell and C. Louis Cuccia, "NASA's Communication Program Examined for the 1980's and 1990's-Part II", Microwave System News, Nov. 1986, pg. 132-139.