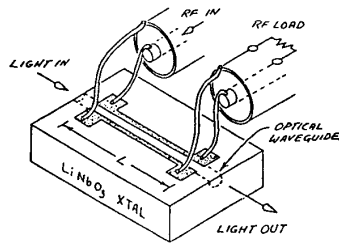


# Novel Millimeter-Wave Electro-optic Modulator

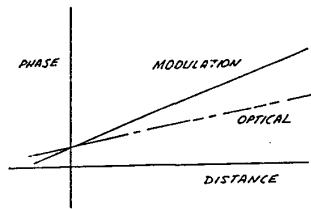
William B. Bridges, Finbar T. Sheehy  
 California Institute of Technology, Pasadena, California, U.S.A.  
 James H. Schaffner  
 Hughes Research Laboratories, Malibu, California, U.S.A.

A waveguide  $\text{LiNbO}_3$  electro-optic modulator has been demonstrated with a novel wave-coupling technique which greatly reduces phase-velocity mismatch. An 8-12 GHz version produces  $48^\circ$  phase modulation with 126 mW of drive power. A 60 GHz version is being built.

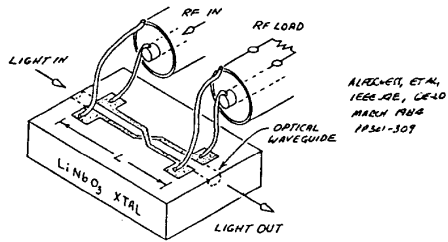
### THE PROBLEM



### PHASE RUNOUT



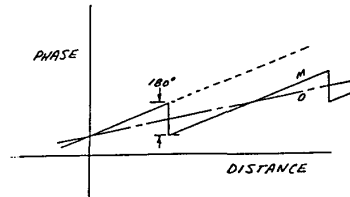
### A SOLUTION



ALBRECHT, ET AL,  
 1988, JEE, 66, 40  
 MARIN, 1988  
 19341-307

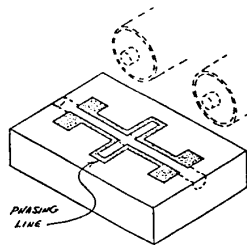
AGE 7-89-90

### PHASE RUNOUT— 180° PHASE REVERSALS



AGE 7-89-90

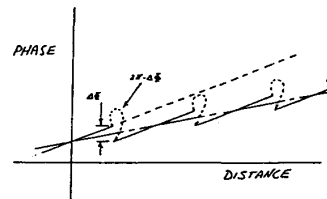
### ANOTHER SOLUTION



J. SCHAFFNER  
 PAPER 1217-18  
 SPIE DE LASE  
 JAN. 1990

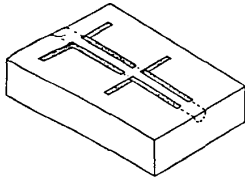
AGE 7-89-90

### PHASE RUNOUT— PERIODIC DELAYS



AGE 7-89-90

IS THERE ANOTHER WAY?



YES!

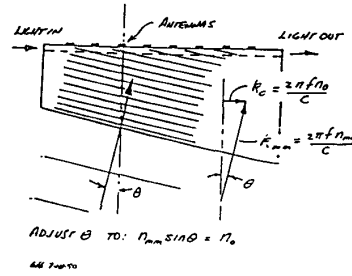
ALL 7-10-70

FEATURES



- BROADBAND - NO CRITICAL PHASING
- NO AXIAL ATTENUATION ALONG ELECTRODES
- NO LEAD PARASITICS

PROPAGATION ANGLE  $\theta$



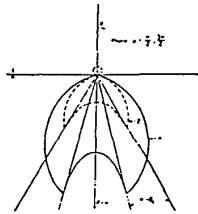
ALL 7-10-70

QUESTIONS



- WILL IT WORK ?
- HOW EFFICIENT IS RF COUPLING ?
- WILL IT SCALE TO MM-WAVES ?
- WILL ANTENNAS WORK ON AN INTERFACE ?

PATTERN: DIPOLE ON DIELECTRIC

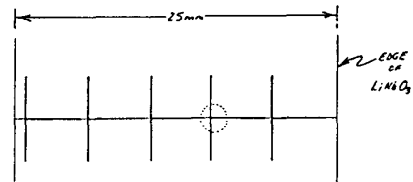


ENGSTEN, PAPAS, & EUCCHI  
RADIO SCIENCE, Vol. 17  
NOV-DEC. 1982  
PP 1557-1566

Fig. 6. Radiation pattern of the horizontal dipole of Figure 1b in the plane  $\phi = \pi/2$ ,  $2\pi/2$  for  $n = 4$  (solid line) and  $n = 2$  (dashed line).

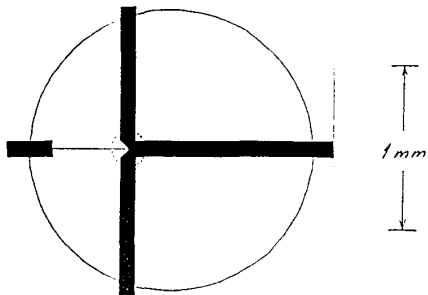
ALL 7-10-70

X-BAND 5 ANTENNA MASK



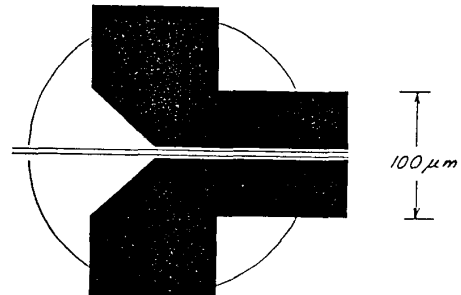
ALL 7-10-70

X-5 MASK, EXPANDED

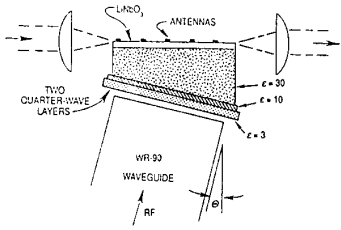


ALL 7-10-80

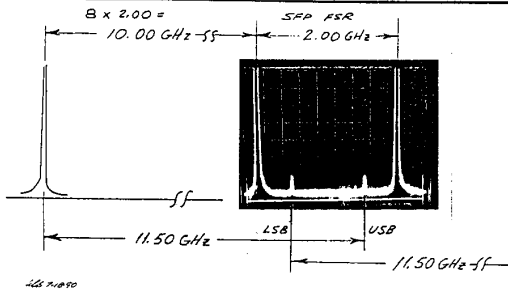
X-5 MASK, EXPANDED MORE



**SCHEMATIC**

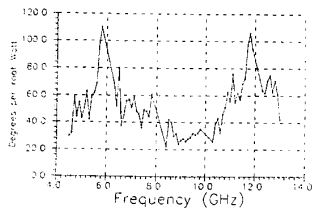
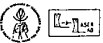


**SCANNING FABRY-PEROT SIDE BANDS @ 11.50 GHz**



24 7-18-90

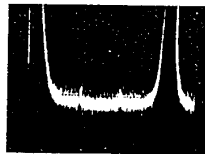
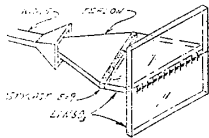
**X-5 RESULTS**



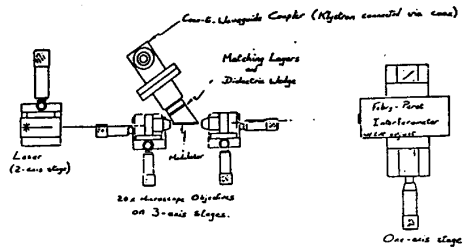
**MM-WAVE RESULTS : 24 OCTOBER**



25mm  $\phi$ -MODULATOR  $\approx$  30 ANTENNAS  
 $P_{RF} \approx 100$  mW @ 63.4 GHz

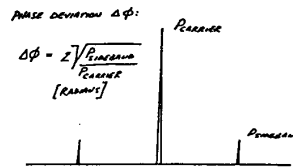


**TEST SETUP**



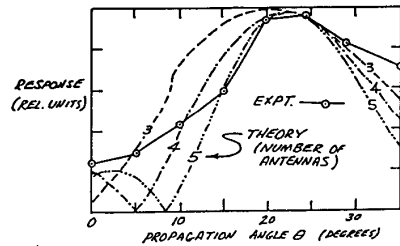
24 7-18-90

**NB&M SPECTRUM**



24 7-18-90

**MODULATION vs ANGLE**



24 7-18-90

**CONCLUSION**



- DEMONSTRATED ANTENNA-COUPLED X-BAND PROTOTYPE PHASE MODULATOR
- FREQUENCY RESPONSE AGREES WITH THEORETICAL MODEL
- ANGLE-DEPENDENCE AGREES WITH PHASE-VELOCITY-MATCHING PICTURE
- CONCEPT SCALABLE TO 500 GHz
- FABRICATING SECOND PROTOTYPE FOR 60 GHz