V-7. A FERROELECTRIC MICROWAVE SWITCH*

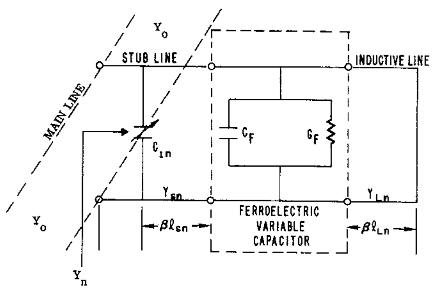
J. W. Amoss and L. J. Lavedan – *Sperry Microwave Electronics Company, Clearwater, Florida*

M. R. Donaldson *University of South Florida, Tampa, Florida*

A. L. Stanford *Georgia Institute of Technology, Atlanta, Georgia*

Introduction. The rapid variation of an impedance shunting a transmission line is a well known technique for switching microwave power (References 1, 2, and 3). The application of a switching voltage to a ferroelectric material provides a convenient means for rapidly varying an impedance between significantly different states. A multistub transmission-reflection type switch actuated by a switching voltage of 1000 volts has been studied. The operation of the switch depends upon the ability of a ferroelectric variable capacitor to change its capacitance upon application of a switching voltage. A change in capacitance represented by a ratio of two to one results in substantial change in the input admittance (Y_n) of the prototype network shunting the transmission line.

Single Stub Switch. The prototype network (shunt stub) is shown schematically in Figure 1 to consist of an inductive line, the ferroelectric variable capacitor, a stub line and an input tuning capacitance. The inductive line is adjusted to resonate the ferroelectric variable capacitor at the mid-band frequency of the switch with the switch in state A. The input tuning capacitor is adjusted to resonate the shunt stub at the mid-band frequency with the switch in state B.



Y_n = input admittance of stub

C_{1n} = input tuning capacitance

Y_{sn}, Y_{Ln} = characteristic admittance of the stub and inductive line, respectively

C_F = ferroelectric capacitance

G_F = conductance of ferroelectric capacitor = $\omega C_F \tan \delta$

$\tan\delta$ = loss tangent of ferroelectric material·

Figure 1. Prototype Shunt Stub

*This work was performed by the Sperry Microwave Electronics Company under Contract No. DA 36-039-AMC-02340 (E) sponsored by the Microwave and Inductive Devices Branch, U. S. Army Electronics Laboratories, Fort Monmouth, New Jersey.

State A corresponds to switch voltage applied and switch closed (isolation) condition while state B applies to switch voltage off or switch open (insertion loss) condition.

It can be shown that isolation and insertion loss of a single stub switch is given by

$L_{1A}^{(\omega)}$ = isolation in db,

$$= 20 \log_{10} \left| 1 + \frac{Y_{1A}^{(\omega)}}{2Y_o} \right| \quad (1)$$

$L_{1B}^{(\omega)}$ = insertion loss in db,

$$= 20 \log_{10} \left| 1 + \frac{Y_{1B}^{(\omega)}}{2Y_o} \right| , \quad (2)$$

$$Y_1^{(\omega)} = \left[Y_n^{(\omega)} \right]_{n = 1} \quad (3)$$

$Y_1^{(\omega)}, Y_{1B}^{(\omega)} = Y_1^{(\omega)}$, state A and state B, respectively.

$$Y_n^{(\omega)} = j\omega C_{1n} + Y_{sn} \left[\frac{Y_{rn}^{(\omega)} \cot \beta \ell_{sn} + jY_{sn}}{Y_{sn} \cot \beta \ell_{sn} + jY_{rn}^{(\omega)}} \right] \quad (4)$$

$$Y_{rn}^{(\omega)} = \omega C_F \tan \delta + j \left(\omega C_F - Y_{Ln} \cot \beta \ell_{Ln}\right). \quad (5)$$

The approximate mid-band isolation and insertion loss for a single stub switch is given by

$L_{1A}^{(\omega_o)}$ = isolation in db at mid-band,

$$\cong 20 \log_{10} \left| 1 + \frac{(Y_{s1})^2}{2Y_o \omega_o C_{FA} \tan \delta_A} \right| \quad (6)$$

$L_{1B}^{(\omega_o)}$ = insertion loss in db at mid-band

$$= 20 \log_{10} \left| 1 + \frac{(Y_{s1})^2 \tan \delta_B}{2Y_o \omega_o C_{FA}} \left(\frac{1 - P}{P}\right) \right| .$$

where

ω_o	= mid-band angular frequency
C_{FA}, C_{FB}	= ferroelectric variable capacitance, state A and state B, respectively
$\tan \delta_A, \tan \delta_B$	= loss tangent of ferroelectric capacitor, state A and state B, respectively
Y_o, Y_{s1}	= characteristic admittance of the transmission and stub line, respectively
P	= fractional change in ferroelectric capacitance
P	$= \frac{C_{FB} - C_{FA}}{C_{FB}}$.

Equations (6) and (7) have been plotted in Figure 2 for a typical set of parameter values. Although reasonably narrow band, the single stub switch nominally exhibits 20 db isolation with one to two db insertion loss.

Since bandwidths of the order of ten percent were desired, multistub switches were considered.

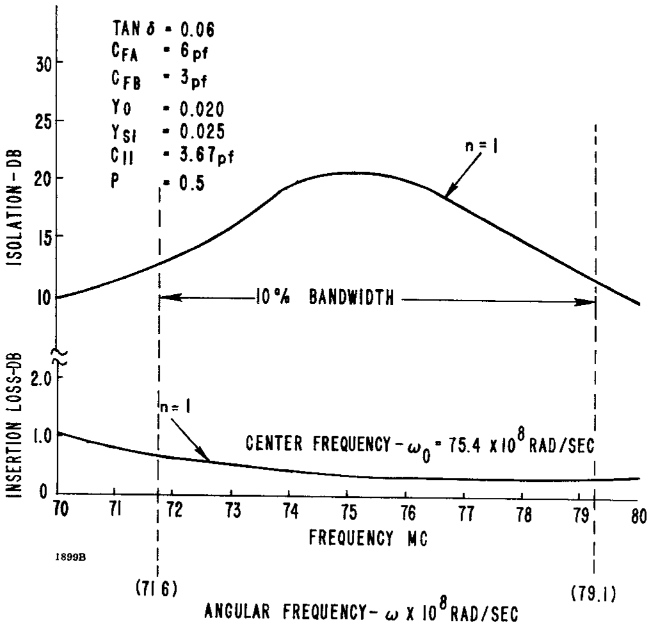


Figure 2. Theoretical Curves of Isolation and Insertion Loss for a Single Stub Switch

Multistub Switch. The multistub switch consists of n prototype shunt stubs nominally spaced at $\lambda/4$ intervals along the transmission line as shown in Figure 3.

Isolation and insertion loss for the multistub switch may be expressed as follows:

$$L_{nA} = 20 \log_{10} \left| \frac{C_{nA}}{2Y_o} \right| \text{ db} \tag{8}$$

$$L_{nB} = 20 \log_{10} \left| \frac{C_{nB}}{2Y_o} \right| \text{ db.} \tag{9}$$

where

C_{nA}, C_{nB} = overall network chain matrix parameter, C_n, state A and state B, respectively

$$C_n = \frac{I_1}{V_2} \bigg|_{I_2 = 0.}$$

Equations (8) and (9) have been evaluated with the use of a digital computer and plotted in Figure 4 for several values of the parameters.

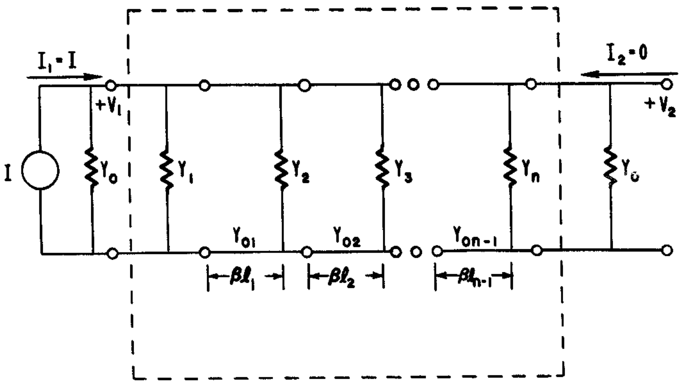


Figure 3. Multistub Ferroelectric Switch Configuration

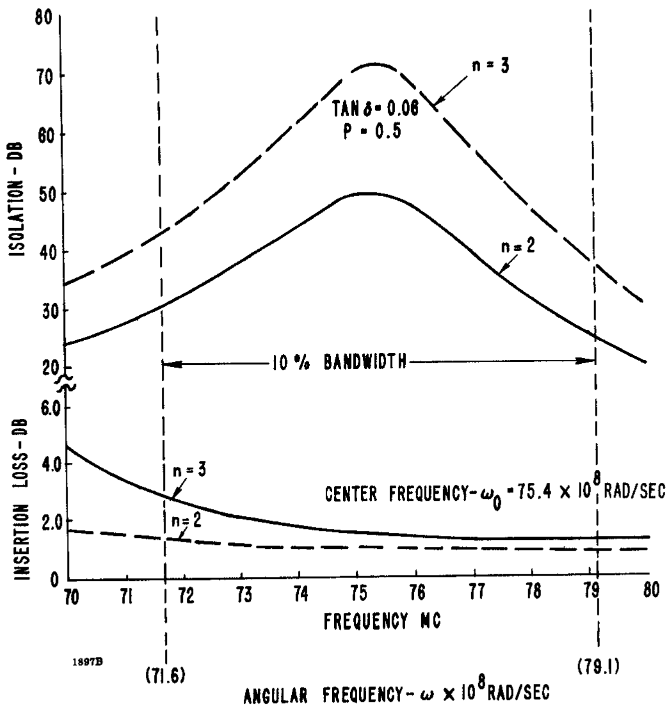


Figure 4. Theoretical Curves of Isolation and Insertion Loss for a Two Stub and a Three Stub Switch

Experimental Results. A two stub and a three stub ferroelectric switch were fabricated using lead strontium titanate $Pb_{0.315}Sr_{0.685}TiO_3$ as the ferroelectric material. The nominal parameters of the material are:

$$\tan \delta \cong 0.06$$

$$C_{FB} = 10 \text{ pf (for 2 stub), 7 pf (for 3 stub) (zero volts applied)}$$

$$C_{FA} = 4 \text{ pf (for 2 stub), 3 pf (for 3 stub) (with 1000 volts applied).}$$

Experimental data are plotted in Figure 5. Figure 6 is a sketch of a three stub switch.

Conclusions. The results of this study indicate that ferroelectric switches with an isolation of 40 db, a bandwidth of ten percent and an insertion loss of less than 1.5 db at L-band are feasible. For less than 10 percent bandwidths an insertion loss of less than 1 db and an isolation over 40 db are possible.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Mr. John Agrios and the computer laboratory personnel at USAEL in providing the numerical data related to the computer program portion of this study. The authors also wish to acknowledge the assistance of Mr. Karl Schmidt for preparing many of the curves from the computer data and Dr. J. E. Pippin for contributions to many of the concepts and technical aspects of the overall program.

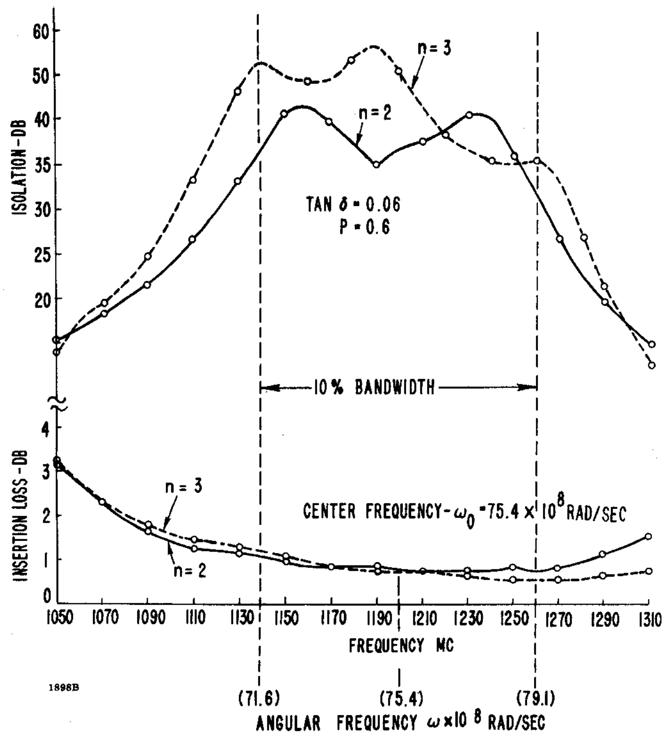


Figure 5. Experimental Data for a Two Stub and Three Stub Switch

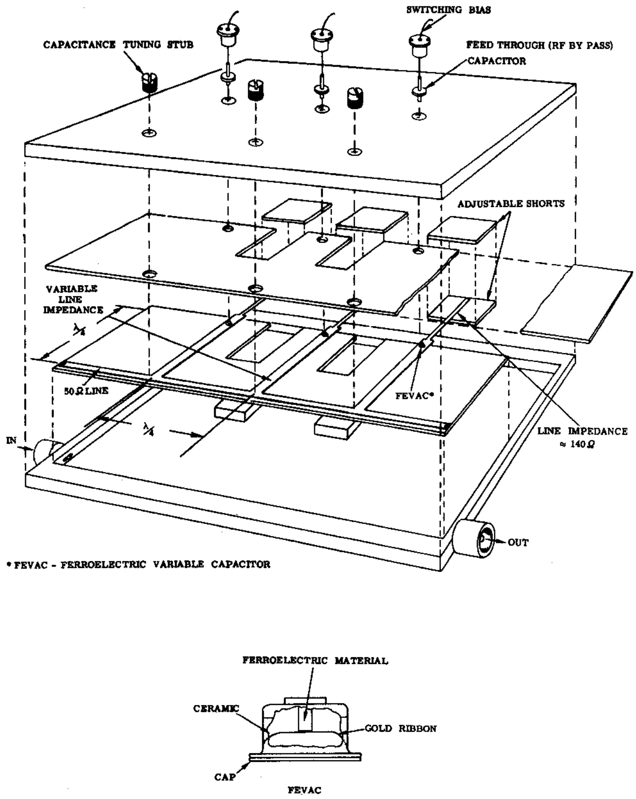


Figure 6. Sketch of a Three Stub Ferroelectric Switch

REFERENCES

1. Garver, R. V., IRE Transactions on MTT, Volume MTT-9, 224, 1961.

2. Garver, R. V., and Rosado, J. A., IRE Transactions on MTT, Volume MTT-10, 302, 1962.

3. Hoover, J. C., IRE Transactions on MTT, Volume MTT-10, 476, 1962.