Research of Faraday-effect based E-band waveguide switches transient characteristics

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Abstract. **The paper presents measurement results of the developed E-band ferrite waveguide switches. The features of the operation of reciprocal switches and the prospects for their application in data transmission systems are considered.**

Keywords: Faraday effect; ferrite switch; E-band; WR-12; radio relay stations

I. INTRODUCTION

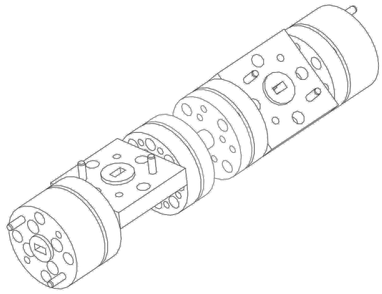
Switches in microwave paths often play a key role in functional microwave devices. According to the principle of operation, microwave switches can be divided into three main classes: mechanical, semiconductor, ferrite. Within the classes, there is also a variety of subclasses that are fundamentally different in physical principles of switching effects. Each has certain advantages. In this paper, Faraday-effect based ferrite switches are considered.

Faraday-effect based switches, like other ferrite microwave devices, have low insertion loss, high microwave transmission power, resistance to external influences and long life. The disadvantages include dynamic characteristics: switching speed, switching energy and a relatively low isolation of ~20 dB (for semiconductor and mechanical switches typical isolation is ~40-60 dB).

The most interesting are Faraday effect ferrite waveguide switches in the frequency range above 20 GHz. They have two main advantages. The first advantage lies in the simplicity of the design of the functional unit itself: a waveguide filled with a longitudinally magnetized ferrite. The second is low insertion losses. For comparison, Pasternak's 60-90 GHz (E-band, WR-12) pin-diode switch insertion loss is: typical 4.5 dB, maximum 6 dB. The ferrite waveguide switch developed by Ferropribor JSC has a maximum insertion loss of 2 dB and mean insertion loss of 1.5 dB in the operating frequency range from 71 GHz to 86 GHz.

II. DESIGN OF FARADAY-EFFECT BASED E-BAND WAVEGUIDE SWITCHES

Faraday-effect based waveguide switch consist of one or two polarization selectors, the waveguide filled (fully or partially) with longitudinally magnetized ferrite until the necessary polarization plane rotation is achieved angle and a magnetic system. Depending on the arrangement of the polarization selectors and their relative position of the flanges, it is possible to implement a reciprocal or non-reciprocal mode of operation of the switch (Fig. 1).



a

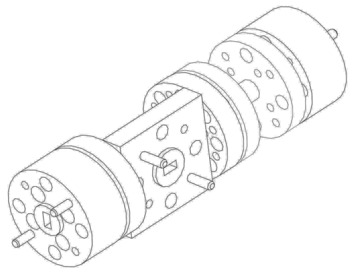


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Fig. 1 a – non-reciprocal SPDT switch, b – reciprocal SPDT switch

A feature of the developed switches is the presence of a group of holes on the connecting flanges of the waveguide ferrite section and the polarization selector, which ensure their precise connection with an angular step of 15 °. This makes it possible to unify the basic assemblies for the switch components (Fig. 2).

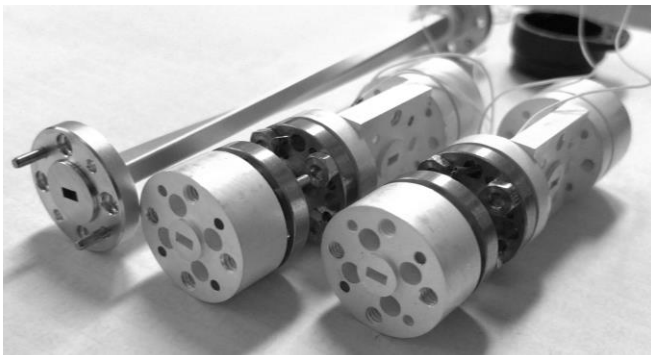


Fig. 2 Samples of SPDT reciprocal Faraday-effect based ferrite waveguide switches

III. MEASUREMENT OF FARADAY-EFFECT BASED E-BAND WAVEGUIDE SWITCHES

The main electrical parameters of ferrite waveguide switches include insertion loss, isolation and VSWR.

The design of measurement bench is shown at Fig.3 It consists of modern network analyzer with cables and transitions, switch driver and PC.

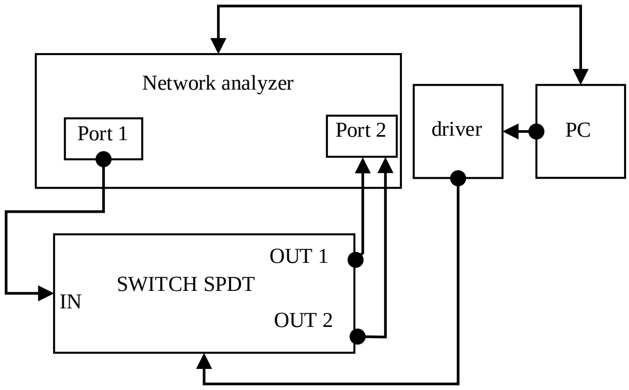
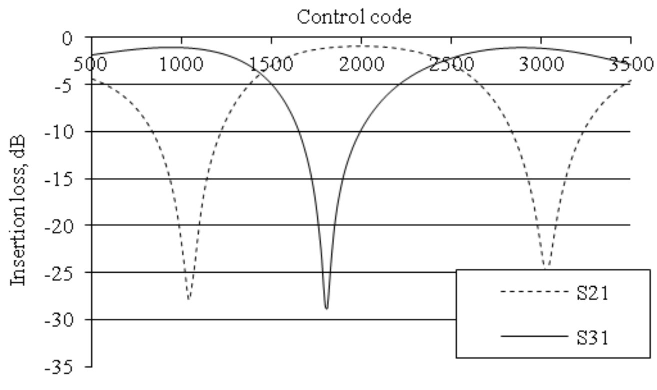


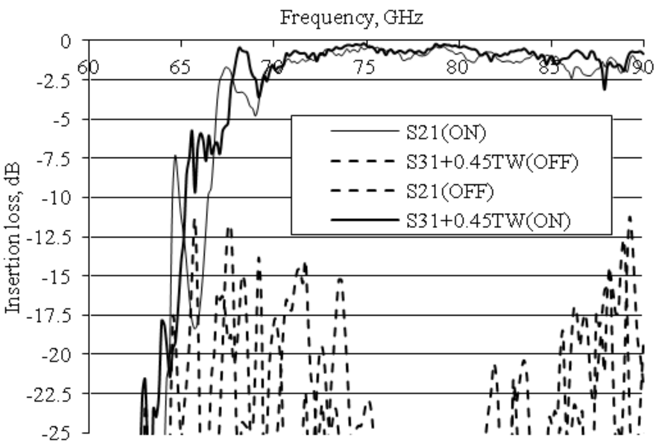
Fig. 3 Ferrite Faraday-effect based waveguide switch measurement bench design

The switch is controlled by changing the current in the control coil located on the ferrite waveguide section. In our case, a special switch driver was developed for this purpose. It is built on operational amplifiers and uses the principle of a bipolar current source with a resolution of less than 50 μA / step. Control code of ~2025 correspond to the zero state (Graph 1).

During the measurements, all S-parameters of the switch are recorded while the current in the coil increase step by step from the minimum negative value to the maximum positive value. Based on the measured data arrays, an automated or manual selection of the optimal current values is performed, which ensures the optimal combination of switch parameters: insertion loss/isolation. Further, the optimal values are written into the driver's memory and it becomes possible to control the switch by simply changing the TTL-input state.



Graph 1. Insertion loss mean value in 71÷86 GHz frequency range



Graph 2. Insertion loss (with adapter removal) over the frequency range at optimal current point .

IV. MEASUREMENT OF ADDITIONAL PARAMETERS OF RECIPROCAL FARADAY-EFFECT BASED E-BAND WAVEGUIDE SWITCHES

Additional parameters include switching time, switching power consumption. Switching time and power consumption are interrelated. In this case, they are determined by the optimal ratio between themselves and are regulated by the number of turns in the coil and wire gauge. Also, in some cases, the transient characteristics of the switch are of interest.

To a first approximation, the switching time of this switch is determined by the current settling time in a coil installed on a waveguide section with a ferrite. In our case, the driver provides three options for the switching process. The first option is setting driver's power circuits to maintain the specified current (Fig. 4). The second option is a short-term operation of the driver's power circuits at about rail output with control of the circuit by feedback of approaching the set current and then entering the current source mode (Fig. 5). The third mode is a quasi-continuous change of the current in the coil for slow switching with a time much longer than the transient time in the control coil.

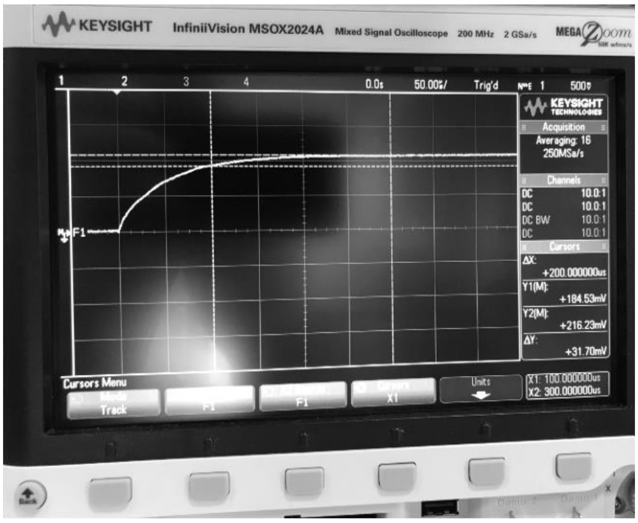


Fig. 4 Coil current transient in optimal power consumption mode. $R_{s.}$=1 Ohm

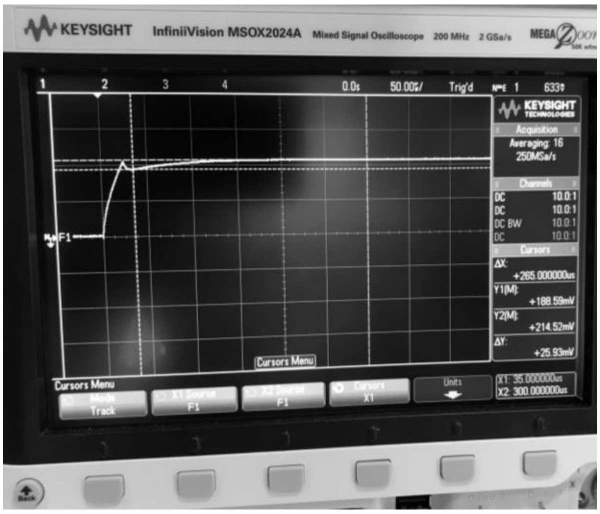
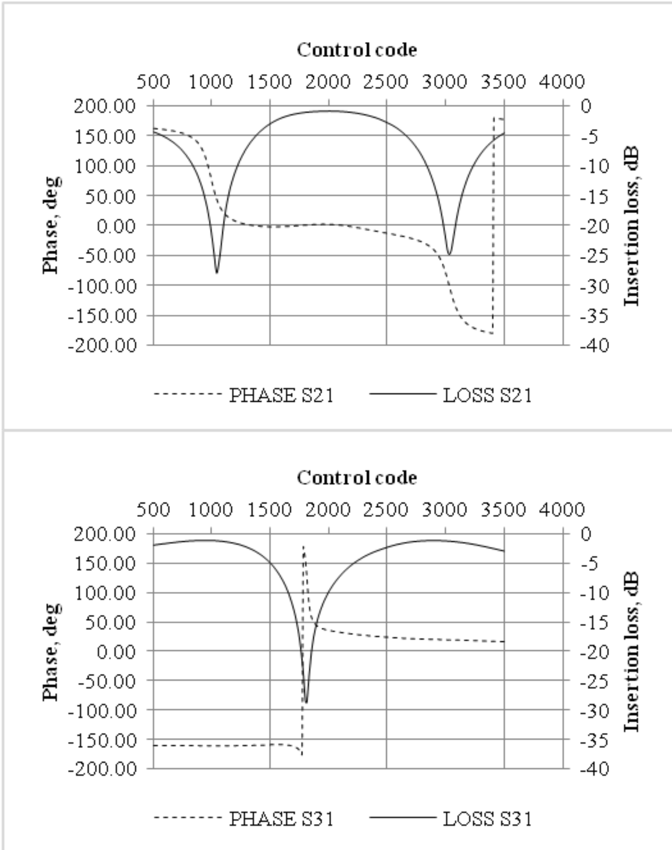


Fig. 5 Coil current transient in fastest switching mode. $R_{s.}$=1 Ohm

Power consumption at the optimal current in the coil is about 0.1 W.

The transient insertion loss characteristics, as already shown at Graph 1, are smooth and proportional to the control coil current change. It is worth noting that this effect is sometimes used for the mode of operation of the switch as an attenuator. At the same time, there is no significant change in the input VSWR, which can be important when operating at continuous power.

Another transient characteristic is the change of the output phase (Graphs 3, 4). Switch has 2 optimal points for Port 3 “ON state” and output phase depends on current polarity, because control code ~1000 corresponds to a “negative” current, while code ~3000 corresponds to a “positive” current.



Graph 3, 4 Transient characteristic of output phase and insertion loss

V. CONCLUSION

Measurement of the transient characteristics of a reciprocal, Faraday-effect based, E-band waveguide switch shows the possibility of its use as an attenuator. It allows to estimate the energy consumption of peripheral auxiliary equipment and possible modes of operation. These measurements clearly demonstrate how these switches work.

To date, the radio frequency bands of 71-76 GHz and 81-86 GHz are allocated for the development, production, modernization and application of advanced line-of-sight radio relay stations (RRS) in the Russian Federation. Corresponding to the frequency range, these switches can be the basis of the components of such systems.

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