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## **VOLTAGE TUNABLE MICROWAVE MULTIBAND FILTERS THROUGH META-INTERFEROMETER**

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**Abstract.** First it has been observed that microwave interferometer with embedded metastructure, meta-surface or meta-atom as voltage-controlled original beam-splitter can show new functionalities, such as specific selective control of line width and intensity, as well line shape and position in multiband spectral filtering. We realize and investigate modified meta-interferometer on basis of rectangular waveguide tee with varactor-loaded conductive resonance elements as a beam splitter at 3 – 6 GHz. It is achieved tunable considerable narrowing and 0.15 – 0.2 GHz shifting of band; switching between stop-band (-25 dB) and pass-band (-2;-5 dB), as well widening and intensification of each filtering band by turns in dependence on resonance element properties and bias voltage 0 – 10 V. The results open up a new approach to implement switchable and tunable multiband microwave filters.

**Key words:** metastructure, microwave, interferometer, beam splitter, tuning, varactor, multiband filters.

### **Introduction**

At present microwave tunable multiband spectral filters, required in multifunctional wireless communication, are subjects of great interest [1]. They play important role for channel selection and signal processing. Basis of the microwave multiband filter is a cascade of different resonators in combination with transmission line. To select required filter electromechanical [2] or electrical switch by varactor diodes [3] is usually used. A simple compact single-band tunable metamaterials filter consists of a micro-strip transmission line with a varactor-loaded split ring resonator

[4]. This approach has been developed and applied in [5–9]. In [5, 6] it has been achieved good band characteristics. In [7] it has been implemented dual-band tunable microwave filters based on two cascaded sections. In [8, 9] it is proposed a metastructure making it possible to achieve nonreciprocal microwave filter that can be controlled by an electrostatic field. But it is very difficult to achieve both tunable and multiband spectral filtering [10].

In this work we implement tunable microwave multiband filtering through modified interferometer on basis of rectangular waveguide tee in which metastructure is embedded as a tunable beam splitter; we will call “meta-interferometer”. Concept of tunable beam splitter based on electro-optical materials embedded in optical Mach-Zehnder interferometer is in progress in classical photonics for quantum information processing [11]. Here we present measurement results of electromagnetic waves transmission coefficient  $T$  in meta-interferometer with different beam-splitters at 3 – 6 GHz. In the first variant varactor-loaded dipole “Butterfly (excited by microwave electric field  $E$ ) is used (Fig. 1a, b). In the second variant beam splitter is a ray of varactor-loaded twice split rings, excited by microwave magnetic field  $h$  (Fig. 1c).

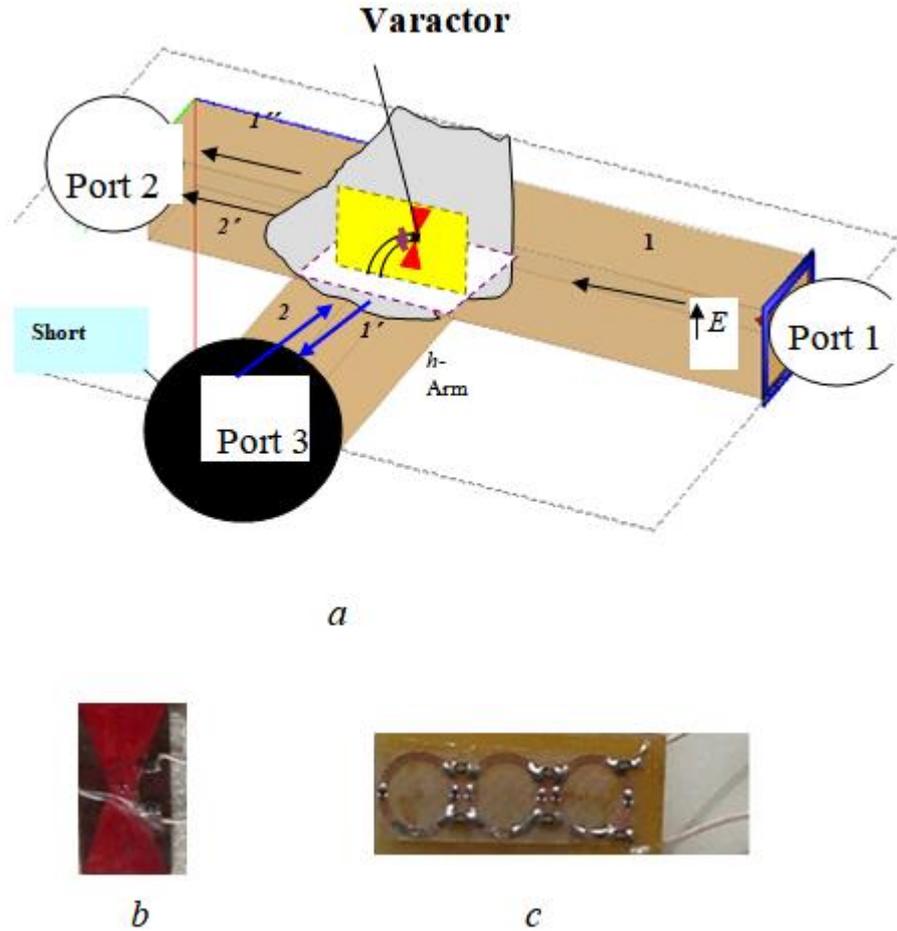
### **Proposed meta-interferometer**

Empty rectangular waveguide  $h$ -plane tee (Port 1 is input) is transformed into interferometer and acts as multiband filter in frequency dependence of transmission in the cases when Port 2 (or 3) is short circuited. In order to increase a number of interference bands it is necessary to increase a length of short circuited Arm. Meta-interferometer (Fig. 1a—scheme, b, c—photographs) contains addition: metastructure as a tunable beam-splitter.

That is individual conductive resonant element in the form of varactor-loaded dipole “Butterfly” or array of twice split rings with varactors. Short circuited side  $h$ -Arm (24x48 mm) has length 250 mm and is removable; Port 2 is output.

For tuning we use varactor MA46H120 (MACOM), with capacitance varying from 1 to 0.15 pF by supplying back bias voltage  $V_{DC}$  from 0 to 10 V. Varactor is welded into the gap of dipole or split ring. We investigate also three dipoles with

fixed capacitance  $C_1 = 6.8$  pF;  $C_2 = 1$ ; and  $C_3 = 0.1$  pF ( $C$ -loaded “Butterfly”). Two variants of meta- interferometer, differing in type of beam splitter, are investigated.



**Fig. 1.** Proposed meta-interferometer:  
*a* with dipole “Butterfly” as a beam splitter (scheme)  
*b* dipole “Butterfly” (photo)  
*c* a ray of magnetically excited twice split rings (photo)

In the first variant copper  $C$ -loaded or varactor-loaded dipole “Butterfly” (20x10 mm) on 2 mm-thick textolite substrate is used. In the second variant beam splitter is a ray of copper twice split rings TSR (diameter of 6.6 mm, each ring contains two varactors). The sizes of elements are chosen so that the resonance response of transmission coefficient  $T$  will be observed at frequency in the given range 3–6 GHz of the voltage standing wave ratio (VSWR) panoramic measurer. Resonance element is placed along axis of main waveguide 1 across the side  $h$ -Arm. Meta-interferometer acquires new functionalities due to resonance properties of beam-splitter and superposition of transmitted, reflected and re-reflected waves. In this case periodicity

violation, change of shape and position of interference bands and possibility of multifarious control is observed in dependence on resonance properties of beam-splitter (width, intensity and frequency of the resonance)

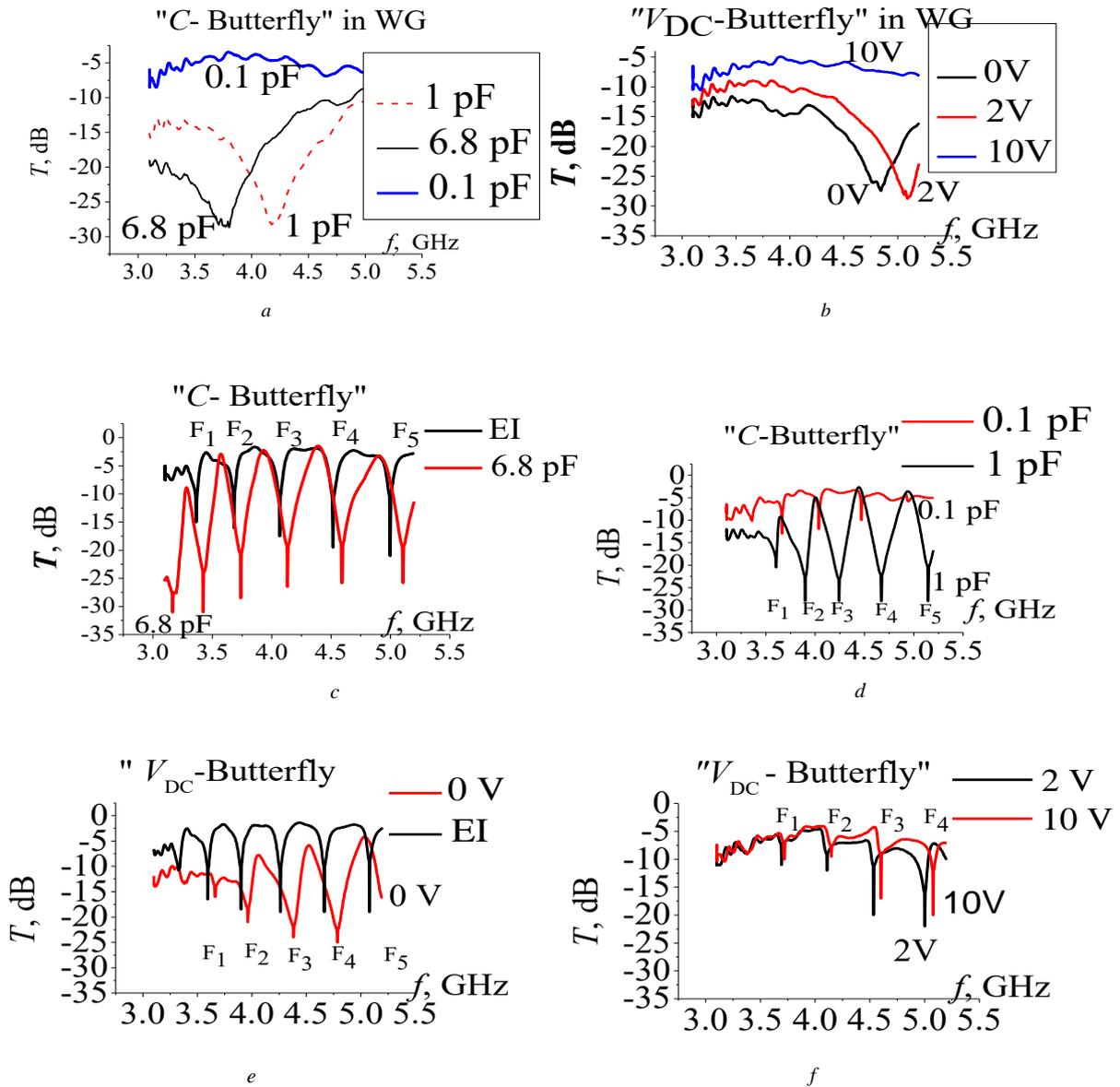
### Measurements results

*With dipole “Butterfly” as a beam splitter:* Figs. 2a, b show typical resonance dependencies of  $T$  (dipole resonances DR) in rectangular waveguide (WG) with different dipoles “Butterfly”:  $C$ -loaded (Fig. 2a) and varactor-loaded (Fig. 2b).

The DR can be tuned by the use of different  $C$ -dipoles with different fixed capacitances or with varactor-loaded “Butterfly” by the application of a bias voltage  $V_{DC}$  to varactor. Meta-interferometer shows multiband spectral filtering, different from five-band spectrum of empty interferometer (EI). In meta-interferometer pass-bands narrowing and stop-bands (F) widening is observed (Fig. 2c, e). Besides, meta-interferometer acquires new capability, such as selective specific control covering several interference bands because of influence of wide dipole resonance DR. In this case intensity, width and frequency ( $f_i$ ) of different interference bands are controlled differently in dependence on DR position ( $f_{DR}$ ). So, Figs. 2c, d show that in the case of  $C$ -loaded “Butterfly” with decrease of  $C$  from 6.8 pF to 1 pF it is observed intensity decrease and narrowing of stop-band  $F_1$  and simultaneously widening of bands  $F_3$  and  $F_4$ ; at the same time  $F_1$  shifts more than other bands, while  $F_5$  position is practically not changed. With  $C = 0.1$  pF it is observed level increase and widening of pass-bands, as well stop-bands narrowing and  $F_5$  disappearance.

Switch between stop (-30 dB) and pass-bands (-2;-5 dB) takes place with change  $C$  from 1 pF to 0.1 pF. Similar specific selective and switchable controllability is observed in the case of varactor-loaded “Butterfly” (Fig. 2 e, f). Pass-bands narrowing and stop-bands widening about EI are different for different interference bands (Fig. 2 e). By variation of  $V_{DC}$  from 0 V to 10 V increase of level and widening of pass-bands as well considerable narrowing and shifting of stop-bands occurs (Fig. 2 f); at the same time different bands are tuned differently. Really, band  $F_1$  (3.66 GHz) is not shifting, while bands  $F_2$  (3.96 GHz);  $F_3$  (4.38 GHz).and  $F_4$  (4,78 GHz) shift to 4.14; 4.6 and 5.1 GHz on 0.18; 0.2 and 0.3 GHz and switch

between stop- (-20; - 25 dB) and pass-bands (-5 dB) takes place.



**Fig. 2.** Dipole "Butterfly": Measured transmission  $T$

a WG,  $C_1=6.8$  pF;  $C_2=1$  pF;  $C_3=0.1$  pF

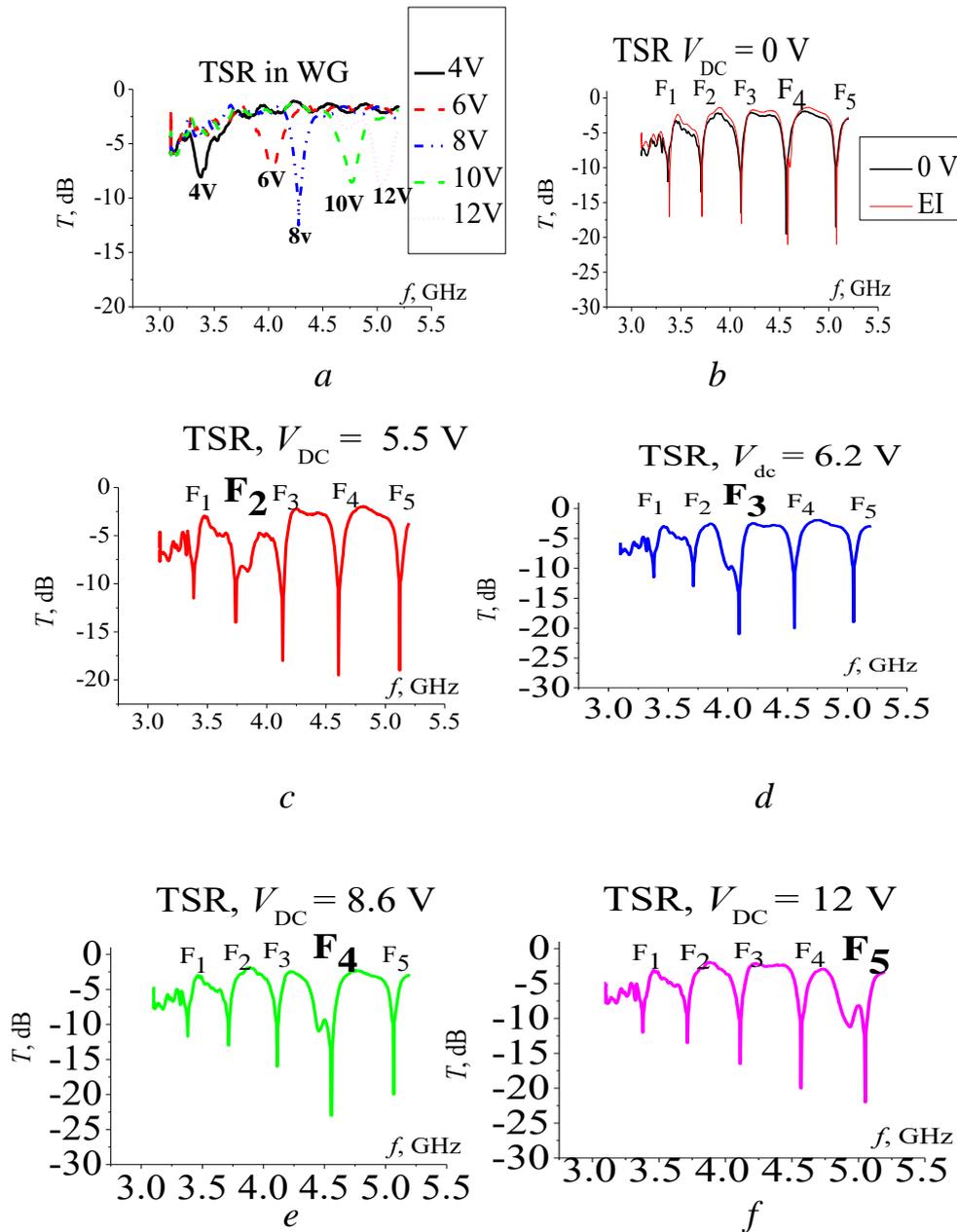
b WG,  $V_{DC} = 0; 2; 10$  V

c Meta-interferometer.  $C_1 = 6.8$  pF in comparison with EI

d Meta-interferometer.  $C_2 = 1; C_3 = 0.1$  pF

e Meta-interferometer.  $V_{DC} = 0$  V in comparison with EI

f Meta-interferometer.  $V_{DC} = 0; 2; 10$  V



**Fig. 3.** Twice split rings TSR. Measured transmission  $T$   
 a WG,  $V_{DC} = 4; 6; 8; 10; 12$  V  
 b Meta-interferometer.  $V_{DC} = 0$  V in comparison with EI  
 c Meta-interferometer.  $V_{DC} = 5.5$  V; change of  $F_2$   
 d Meta-interferometer.  $V_{DC} = 6.2$  V; change of  $F_3$   
 e Meta-interferometer.  $V_{DC} = 8.6$  V; change of  $F_4$   
 f Meta-interferometer.  $V_{DC} = 12$  V; change of  $F_5$

With twice split rings TSR: Results of measurement of frequency dependences of  $T$  in WG with array of varactor-loaded TSR show magnetic resonance (MR) due to ring current induced by  $h$ -field. The MR shifts to higher frequencies with increase of

$V_{DC}$  (Fig. 3a). In Fig. 3b we see that when TSR are embedded in EI, interference dependence of  $T$  is not practically changed. With  $V_{DC}$  variation moving MR can approach individual interference band position. In this case corresponding band is controlled separately without changes of other bands. One can achieve widening and intensification of each stop-band by turns. Fig. 3c demonstrates change of  $F_2$  at  $V_{DC} = 5.5$  V. In Fig. 3d one can see change of  $F_3$  at  $V_{DC} = 6.2$  V. It has been observed also that changes of  $F_4$  and  $F_5$  occur at  $V_{DC} = 8.6$  V and 12 V.

## Conclusion

So, meta-interferometer on basis of rectangular waveguide tee with varactor-loaded dipole “Butterfly” or a ray of twice split rings as an original tunable beam splitter shows specific selective electric controllability of multiband spectral filtering at 3 – 6 GHz in dependence on resonance properties of beam splitter and voltage variation from 0 to 10 V: selective tuning covering several stop-bands; tunable considerable narrowing and 0.15 – 0.2 GHz shifting of defined stop-band; switch between stop (-20; -25 dB) and pass-bands (-5 dB), with “Butterfly”; as well selective controlling of individual band by TSR. The obtained results open up new approach to design microwave multifarious multiband spectral filtering and implement selective voltage tuning, required in multifunctional and multichannel wireless communication.

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