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Reconfigurable Microwave Filters

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1. Introduction

Reconfigurable microwave filters make microwave transceivers adaptable to multiple bands of operation using a single filter, which is highly desirable in today's communications with evermore growing wireless applications. Tunable filters can replace the necessity of switching between several filters to have more than one filter response by introducing tuning elements embedded into a filter topology.

Microwave tunable filters can be divided in two groups, filters with discrete tuning, and filters with continuous tuning. Filter topologies presenting a discrete tuning generally use PIN diodes or MEMS switches. On the other hand, filter topologies using varactor diodes, MEMS capacitors, ferroelectric materials or ferromagnetic materials are frequently used to obtain a continuous tuning device. Filter topologies can mix continuous and discrete tuning by combining tuning elements as well, e.g. the use of switches and varactors on a filter topology can form part of a discrete and continuous tuned device.

Center frequency is the most common filter parameter to reconfigure. Fewer designs reconfigure other parameters, such as the bandwidth or selectivity. When deciding which technology is adequate for a given application, the designer must consider the following issues: cost, power consumption, size, performance and operating frequency. This chapter intends to provide a broad view of the microwave reconfigurable filters field, where different technologies used to reconfigure filters are discussed through different chapter sections, and finally an overall view of the field is given in the conclusions section at the end of the chapter.

This chapter starts discussing filters that use active devices as tuning elements in section 2; these include the PIN diode, the varactor diode, the transistor and Monolithic Microwave Integrated Circuit (MMIC) implementation. Section 3 discusses the use of Micro Electro Mechanical Systems (MEMS) as tuning elements on filter topologies; the section discusses the use of MEMS switches and MEMS varactors. Section 4 contains tunable filters using ferroelectric materials, where devices using the most common ferroelectrics are discussed. Section 5 contains filters that use ferromagnetic materials as tuning elements, the section discusses circuits using Yttrium-Iron-Garnet (YIG) films and other ferromagnetic tuning mechanisms.

Section 6 describes devices that combine some of the technologies discussed in previous sections to achieve reconfigurable filter parameters. Section 7 contains a discussion of traditional filter tuning techniques using dielectric or metallic mechanically adjustable tuning screws. Section 8 gives an overall conclusion of this chapter.

2. Tunable filters using active devices

This section covers tunable filters that use semiconductor based tuning elements. Devices using diodes are attractive below 10 GHz where diodes can still show quality factors above 50 with low bias voltages. Diodes usually involve simple packages and can be mounted on microwave boards, many of these designs are thought as potential monolithic designs. This section covers tunable filters that use PIN diodes, varactor diodes, transistors and ends with a discussion on monolithic designs.

2.1. Tunable filters using PIN diodes

PIN diodes are frequently used to produce reconfigurable discrete states on a filter response, and are very attractive for low cost implementations. In this section, tunable filters using PIN diodes are discussed in distributed and lumped topologies as well a design using periodic structures.

2.1.1. Distributed designs

Recently in (Brito-Brito et al., 2008) the relation between fractional bandwidth and the reactance slope parameter of switchable decoupling resonators has been discussed. This technique has been used to implement two switchable bandstop filters (Brito-Brito et al., 2009 b); these filters can switch between two center frequency states, each having a defined fractional bandwidth. The filters have been implemented to provide the same fractional bandwidth at both center frequencies or different bandwidths defined by the shape of bended switchable resonator extensions, these two topologies are shown in Fig. 1.

The filter presented in (Lugo & Papapolymerou, 2004) can produce broad and narrow bandwidths by modifying inter-resonator couplings. The filter in (Koochakzadeh & Abbaspour-Tamijani, 2007) covers a frequency tuning range from 290 to 600 MHz in four steps using ten PIN diodes.

A tunable side coupled resonator filter with three center frequency states and two possible bandwidths for each state can be found in (Lugo & Papapolymerou, 2006 a). A reconfigurable bandpass filter for WiFi and UMTS transmit standards (Brito-Brito et al., 2009 a) is shown in Fig. 2, the filter has been designed to precisely provide the center frequency and bandwidth required for each application with low loss and low power consumption, since it only uses two PIN diodes.

The reconfigurable bandpass filter in (Lacombe, 1984) can obtain a pseudo all pass response or a bandpass response using PIN diodes. A Dual mode resonator filter can be found in (Lugo & Papapolymerou, 2005), the filter uses a triangular patch resonator to achieve a two state reconfigurable bandwidth. A reconfigurable bandwidth using a dual mode square resonator can be found in (Lugo et al., 2005).

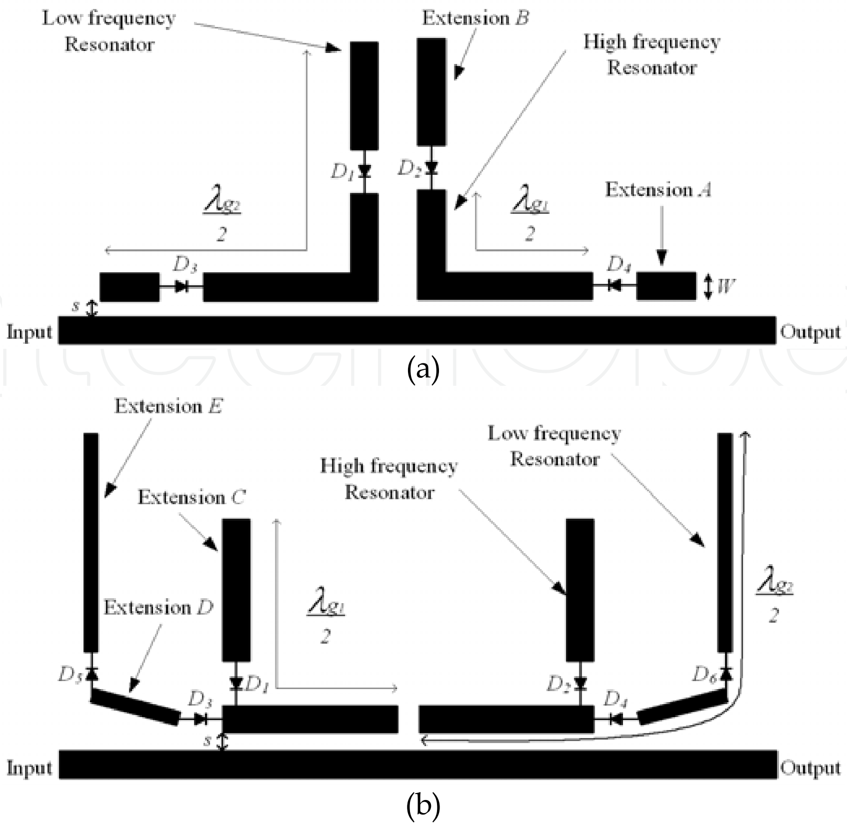

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Fig. 1. Two state switchable bandstop filters using PIN diodes a) constant bandwidth b) different bandwidth, taken from (Brito-Brito et al., 2009 b).

Other dual mode resonator filter is presented in (Lugo & Papapolymerou, 2006 b), this filter has an asymmetrical filter response, and can tune its center frequency, and transmission zero position using a modified square resonator. The filter in (Karim et al., 2008) can switch from a bandstop to a bandpass response for ultra wideband applications using four PIN diodes. A tunable non uniform microstrip combline filter with a reconfigurable center frequency of over an octave in the UHF band can be found in (Koochakzadeh & Abbaspour-Tamijani, 2008), the filter can maintain a constant bandwidth over the center frequency tuning range.

2.1.2. Lumped element designs

Lumped element filter designs using PIN diodes include a reconfigurable bandwidth design at 10 GHz able to switch between a 500 MHz and a 1500 MHz bandwidth (Rauscher, 2003). The filter presented in (Chen & Wang, 2007) uses low-temperature co-fired ceramic technology and can switch between two center frequency states.

2.1.3. Filters using periodic structures

The filter in (Karim et al., 2006) switches between a bandstop and a bandpass response using electromagnetic band gap periodic structures on a coplanar ground plane; the filter is centered at 7.3 GHz.

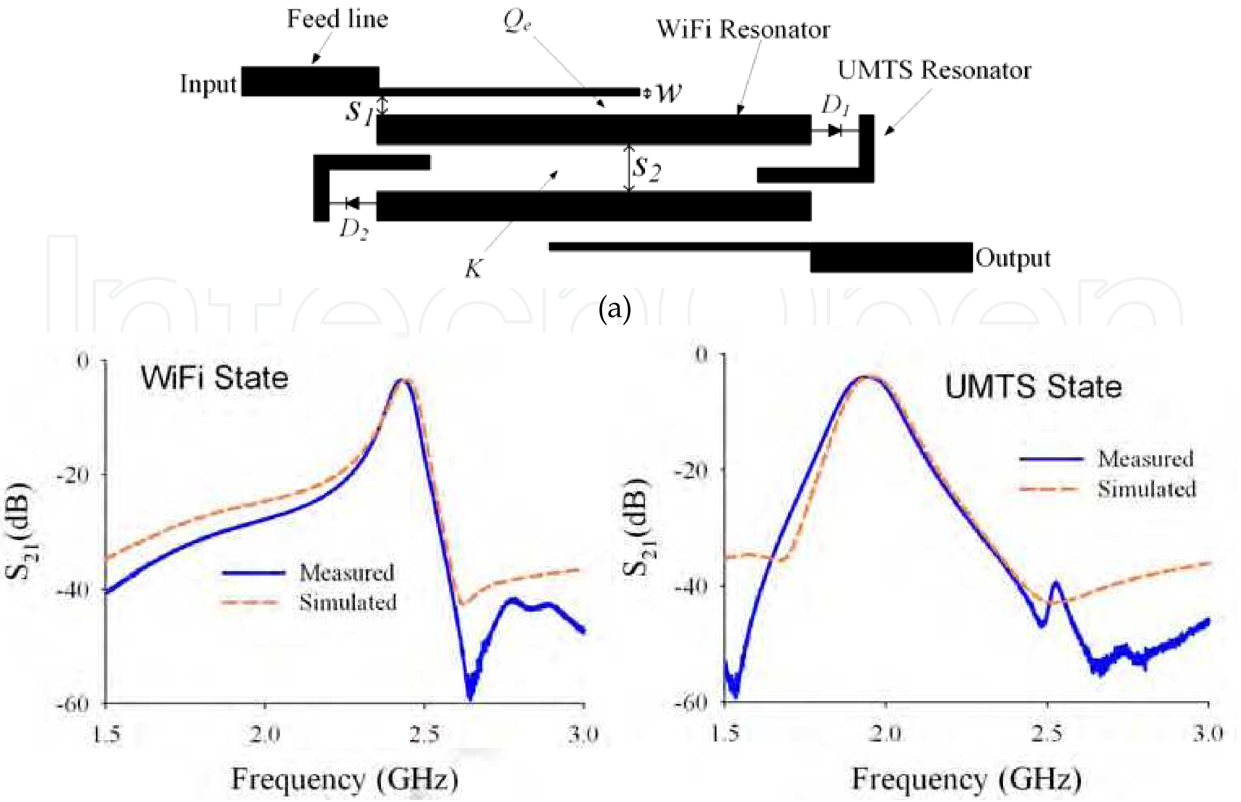

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Fig. 2. Switchable bandpass filter using PIN diodes a) topology b) filter response, taken from (Brito-Brito et al., 2009 a).

2.2. Tunable filters using varactor diodes

Varactors are typically used for continuous tuned filters. Varactor diodes use the change in the depletion layer capacitance of a p-n junction as a function of applied bias voltage. Varactor tuned devices have been used for high tuning speeds; these devices do not exhibit hysteresis. Tuning speeds of varactor tuned filters are limited only by the time constant of the bias circuit. Varactor based tunable filters are mainly distributed designs as covered in this section.

The filter in (Musoll-Anguiano et al., 2009) can reconfigure center frequency, bandwidth and selectivity, resulting in a fully adaptable bandstop design. A photograph of this filter is shown in Fig. 3. The filter response when tuning these three parameters is shown in Fig. 4.

The filter in (Chung et al., 2005) can tune center frequency or bandwidth using a compact hairpin like resonator. The combline filters in (Hunter & Rhodes, 1982 a), (Hunter & Rhodes, 1982 b), (Sanchez-Renedo et al., 2005) and (Brown & Rebeiz, 2000) use suspended stripline transmission lines. The first design is a bandpass filter, and the second one is a bandstop filter. The bandpass design can tune its center frequency showing a good impedance matching for the different filter states. The third design provides both center frequency and bandwidth control on a bandpass filter topology. The fourth design is a bandpass filter with a reconfigurable center frequency, respectively.

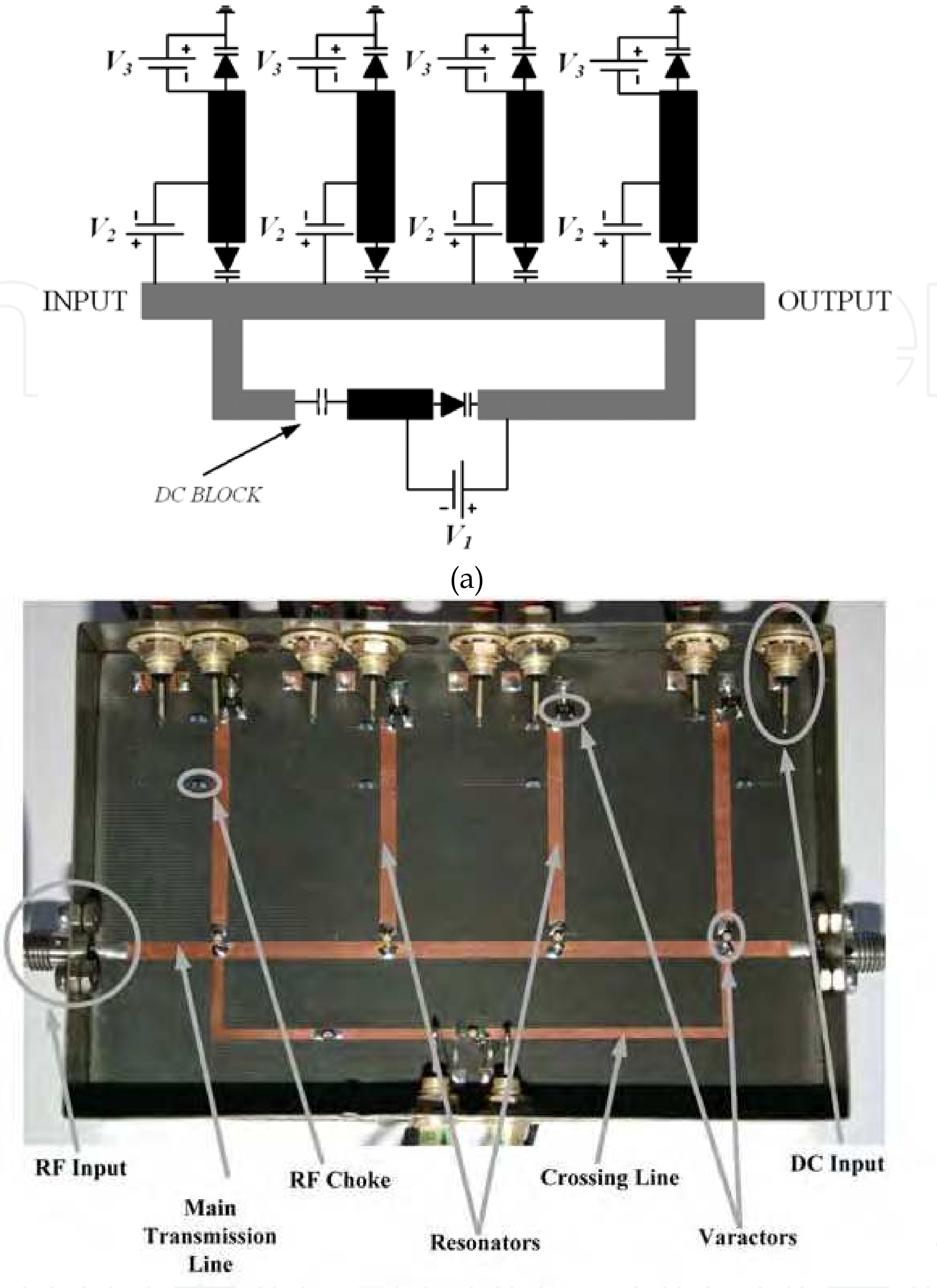

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Fig. 3. Tunable bandstop filter using varactor diodes a) topology b) photography of the filter, taken from (Musoll-Anguiano et al., 2009).

In (Makimoto & Sagawa, 1986) a tunable bandpass filter using microstrip varactor loaded ring resonators is demonstrated, the device can reconfigure its center frequency. In (Liang & Zhu, 2001) a filter mixing combline and hairpin like resonators to achieve transmission zeros on the sides of the passband is presented, the device can tune its center frequency.

2.3. Tunable filters using PIN and varactor diodes

This section reviews filters which combine PIN and Varactor diodes, this results in filter topologies with discrete and continuous tuning.

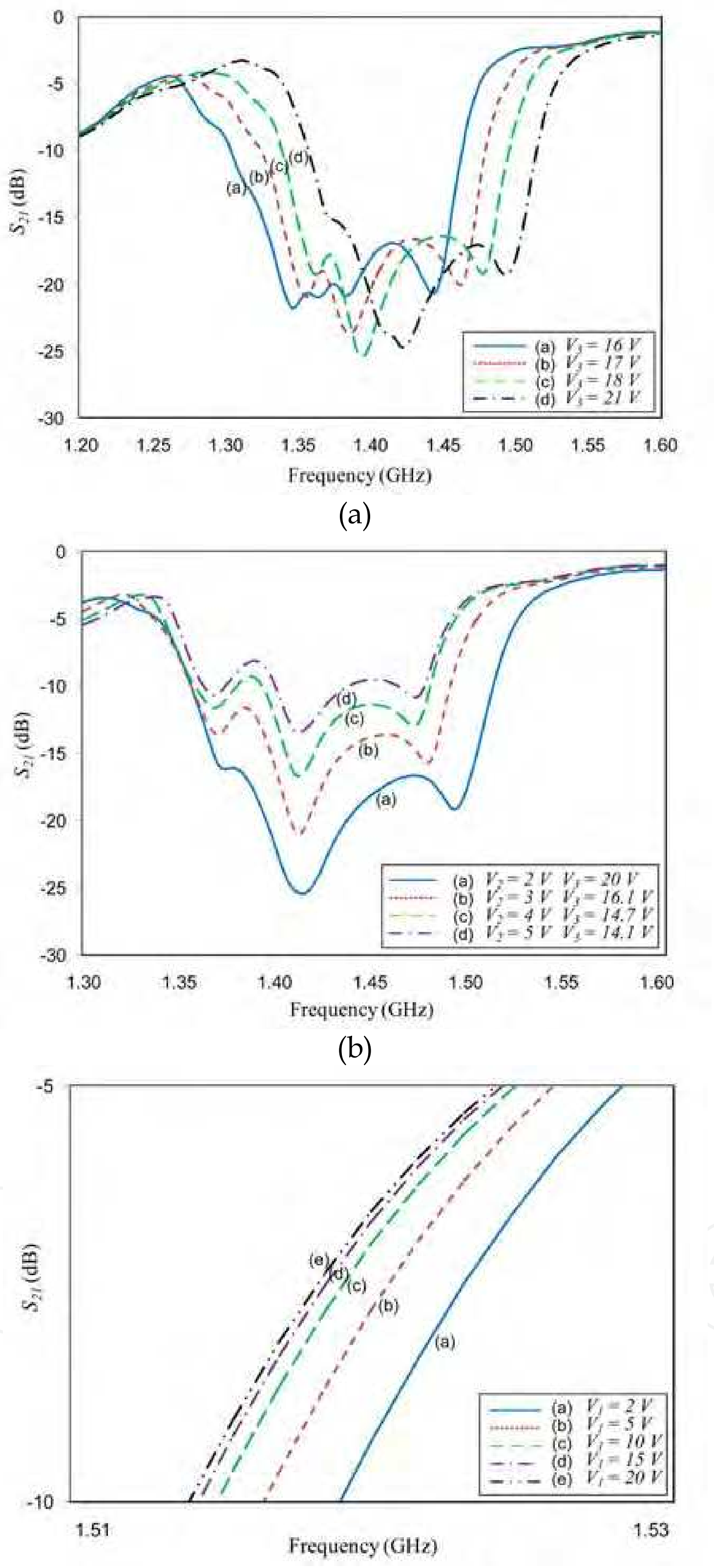

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Fig. 4. Tunable bandstop filter measured responses according to applied bias voltages a) center frequency tuning b) bandwidth tuning c) selectivity tuning, taken from (Musoll-Anguiano et al., 2009).

PIN diodes have been used to vary resonator length for frequency tuning and varactor diodes to modify the bandwidth at each center frequency state in (Carey-Smith & Warr, 2007). This results in discrete center frequency tuning, and continuous bandwidth tuning.

2.4. Tunable filters using transistors

A gallium arsenide field effect transistor has been used as a tuning element in (Torregrosa-Penalva et al., 2002), the filter topology and frequency response is shown in Fig. 5; the device is based on a combline topology and can tune its center frequency.

Center frequency tuning has been achieved on a two pole filter configuration using two metal semiconductor field effect transistors in (Lin & Itoh, 1992), one transistor is used for center frequency tuning and the other to provide a negative resistance to the circuit. The negative resistance technique can raise the resonator unloaded quality factor resulting in an improved filter response.

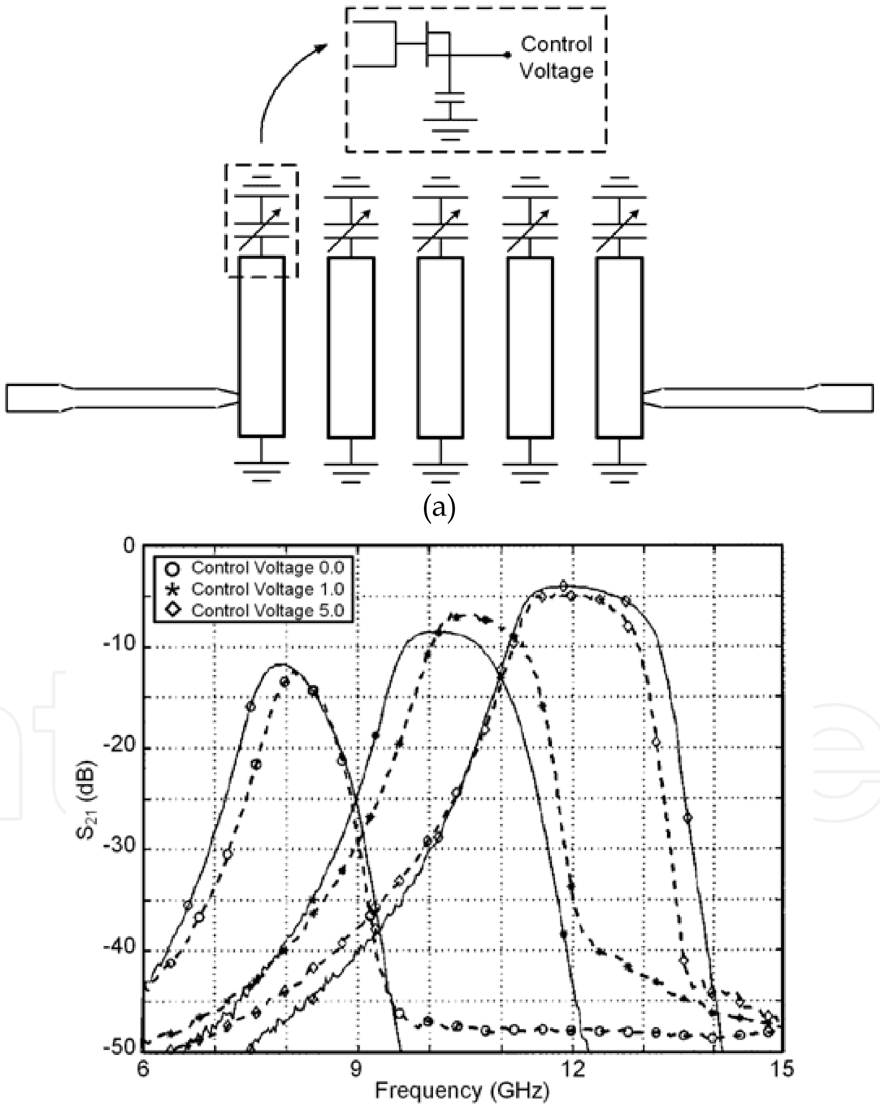

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Fig. 5. Tunable bandpass filter using transistors a) topology b) filter response, taken from (Torregrosa-Penalva et al., 2002).

2.5. Tunable filters using transistors and varactor diodes

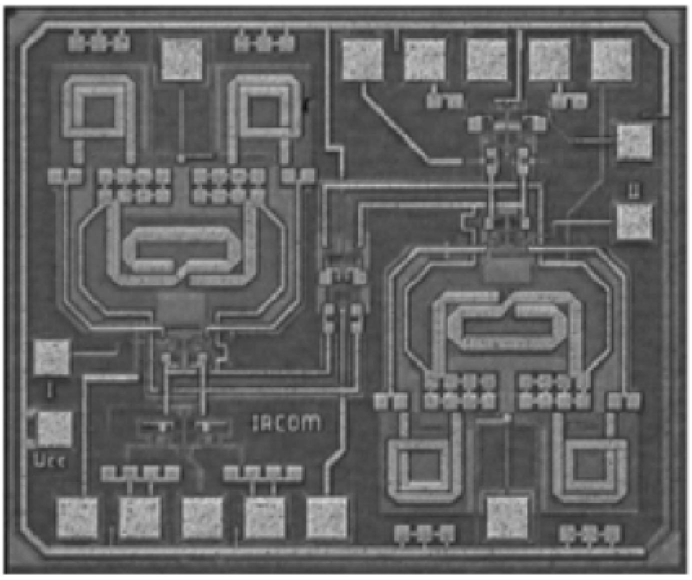
To compensate for filter losses, like those resulting from using a varactor diode, a negative resistance circuit using transistors can be added to the design. This technique has been used in (Chandler et al., 1993 b) where bandstop and bandpass filters are demonstrated, the transistor used was a silicon bi-polar transistor. In (Chandler et al., 1993 a) a bandpass filter is demonstrated using silicon bi-polar transistors as well. Finally in (Chang & Itoh, 1990) metal semiconductor field effect transistors were used on a bandpass filter topology.

2.6. MMIC Tunable filters

The silicon integrated reconfigurable filter in (Darfeuille et al., 2006) can tune center frequency, bandwidth and transmission gain, a photography and center frequency response of the chip is shown on Fig. 6. Two K-band filter designs using 0.15 μm gallium arsenide technology have been reported in (Fan et al., 2005), both devices use negative resistance compensation for losses. The filter in (Takahashi et al., 2006) has an operating frequency range of around 120 GHz; the device can tune its center frequency or bandwidth, the device uses indium phosphide high-electron-mobility transistors. The tunable filter in (Wu & Chan, 1997) uses gallium arsenide metal semiconductor field effect transistors and provides frequency tuning with high resonator unloaded quality factors obtained using a negative resistance circuit which is also used as a tuning element.

3. Tunable filters using MEMS

RF MEMS reconfigurable devices have good compatibility with technologies used in semiconductor industries. They offer small size and good integration capabilities with microwave electronics. RF MEMS in general require low currents to be operated, thus they consume low power compared to solid state devices, and they also can exhibit linear transmission with low signal distortion. This section contains tunable filters that use MEMS switches or MEMS varactors as tuning elements.



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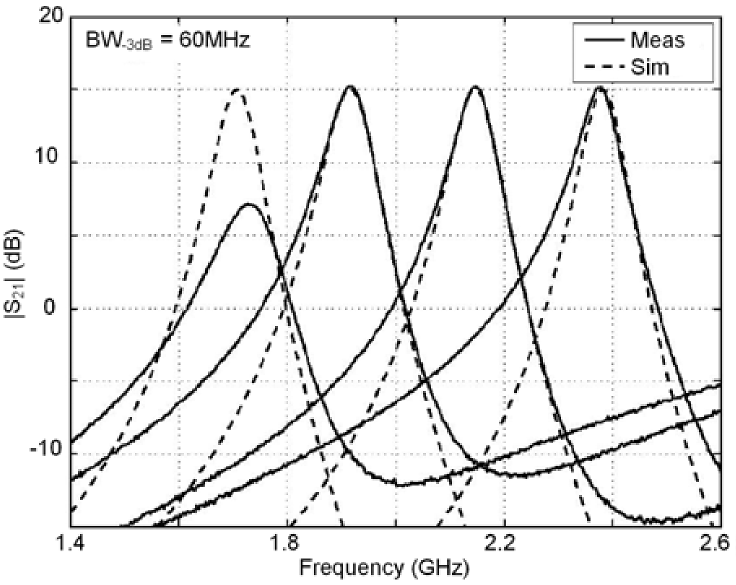

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Fig. 6. MMIC tuneable bandpass filter a) fabricated chip b) filter response, taken from (Darfeuille et al., 2006)

3.1. Tunable filters using MEMS switches

This section reviews several filter topologies using MEMS switches to produce discrete tuning of reconfigurable parameters. The switches can be either a cantilever or a bridge type, and can be capacitive type switches or direct contact switches. Switches can have two states: on or off. Direct contact switches will generally make a metal to metal contact in the on state, direct contact switches are commonly used for low frequency applications. Capacitive switches will present two capacitances, one in the on state and another one in the off state, these switches can be used for high frequency operation.

3.1.1. Filters using direct contact switches

This section discusses filters that use direct contact switches as tuning elements. The switches have an off state when the switch membrane is suspended and does not make contact with a bottom metallic pad. The switch in the on position results in a metal to metal contact of the switch membrane with a bottom metallic pad. Direct contact metal switches can be found as cantilever type, and bridge type. The switch on and off position is controlled by a bias voltage between the switch membrane and actuation electrodes. This section contains tunable filters in distributed designs, lumped element designs and finally a filter using periodic structures is described.

3.1.1.1. Distributed designs

A microstrip bandpass filter using hairpin resonators with direct contact cantilever switches on the end of the resonators has been reported in (Ocera et al., 2006), the cantilever switches are used to enlarge the hairpin resonators when the switches are in the on state, thus tuning the device center frequency; a photography of the filter and cantilever switch is shown in Fig. 7, as well as its center frequency response. Tunable slotline resonators printed on a microstrip ground plane have been used to make a lowpass filter using commercial MEMS switches to short-circuit the slot resonators in (Zhang & Mansour, 2007).

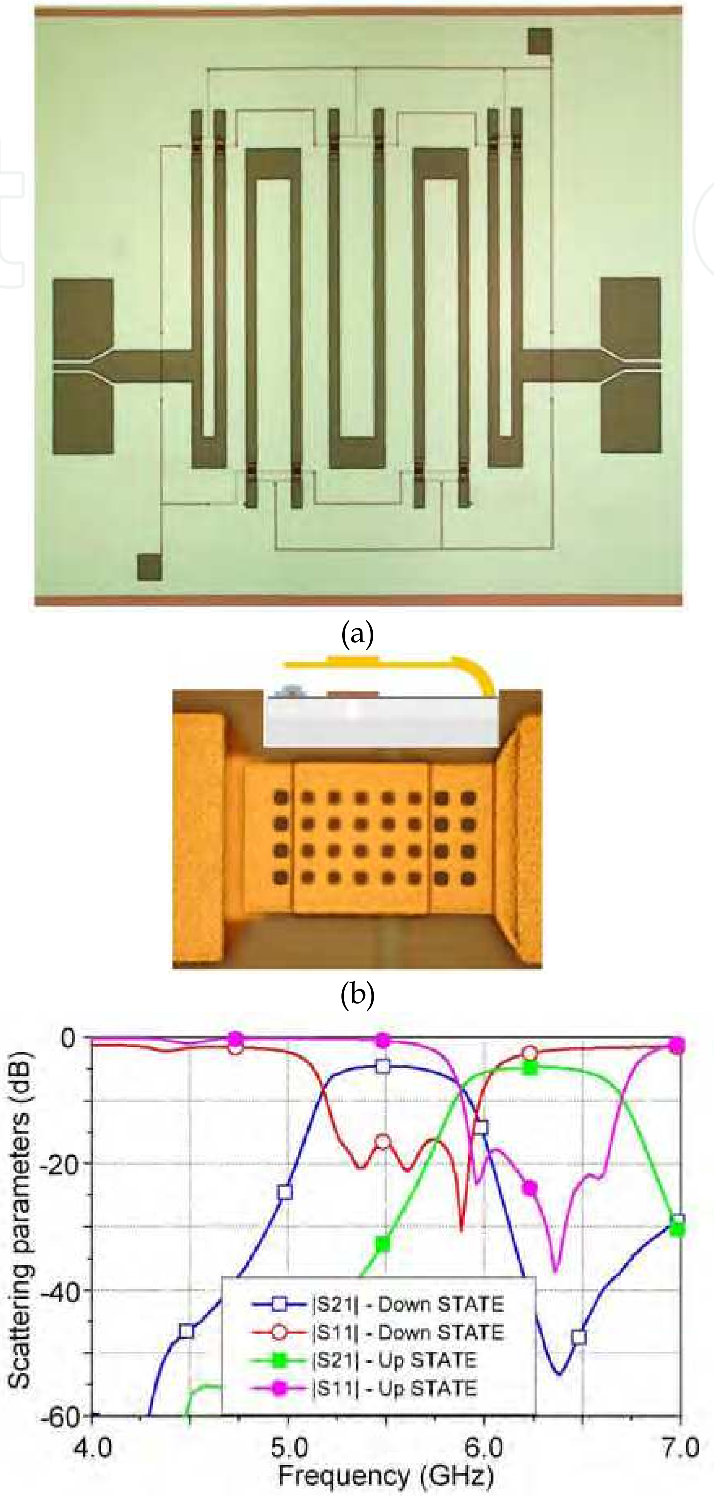

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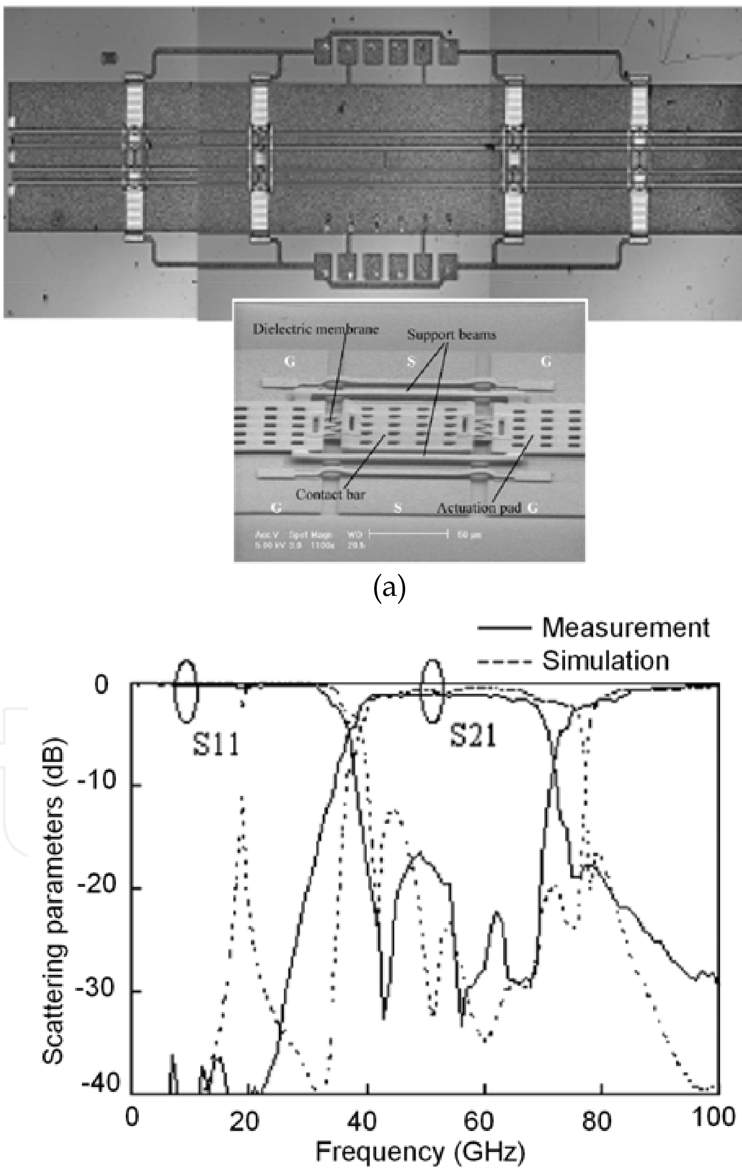
Fig. 7. Tunable bandpass filter using direct contact MEMS cantilever switches a) photography b) direct contact MEMS cantilever switch c) filter response, taken from (Ocera et al., 2006)

3.1.1.2. Lumped element designs

The bandpass lumped element tunable filter in (Entesari et al., 2007) uses commercial switches on an FR4 substrate; the device can reconfigure its center frequency from 25 to 75 MHz. A filter in (Kim et al., 2006) uses direct contact switches for wireless local area network applications to route the microwave signal on two different paths resulting in a two state reconfigurable center frequency filter.

3.1.1.3. Filters using periodic structures

In (Park et al., 2005) a lowpass and a bandpass filter using direct contact switches have been designed and fabricated, the switches can make single and multiple contacts on coplanar transmission lines with periodic structures. Fig. 8 shows the fabricated bandpass filter and its frequency response.



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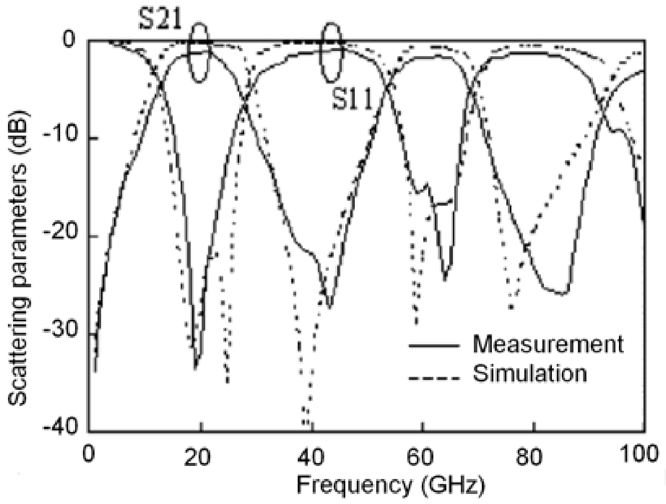

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Fig. 8. Tunable bandpass filter using direct contact MEMS switches a) photography of the fabricated filter b) filter response when the switches are in the off state c) filter response when the switches are in the on state, taken from (Park et al., 2005)

3.1.2. Filters using capacitive switches

This section contains filters that use capacitive type MEMS switches as tuning elements. The switches can produce two capacitances, one defined for the switch in the off state, and the other one is defined when the switch is in the on state. The two states are controlled by a bias voltage between the switch membrane and actuation electrodes. The capacitive switches can be of a cantilever type or a bridge type. This section contains designs using distributed and lumped elements.

3.1.2.1. Distributed designs

A reconfigurable filter for wireless local area network applications can be found in (Park et al., 2006), the filter uses open loop ring resonators loaded with fixed metal air metal capacitors and capacitive switches. Capacitive bridge type MEMS switches have been used to load coplanar resonators in (Entesari & Rebeiz, 2005 b), were 16 different center frequency states have been achieved.

A switchable interdigital coplanar filter can be found in (Fourn et al., 2003 a), the design has two center frequency states, achieved by using a capacitive MEMS cantilever switch on the ends of coplanar resonators. MEMS cantilever capacitive switches have also been used in (Ong & Okoniewski, 2008), on a pair of microstrip parallel coupled line filters to achieve two center frequency states.

3.1.2.2. Lumped element designs

A bandpass filter with a center frequency tuning range from 110 MHz to 2.8 GHz has been reported in (Brank et al., 2001), the design uses capacitive switches to form variable capacitor banks to reconfigure center frequency, the device also uses metal insulator metal capacitors on the lumped topology. One of the filters in (Kim et al., 2006) uses a capacitive switch bank to reconfigure filter center frequency for wireless local area network applications. A differential filter that can tune its frequency from 6.5 to 10 GHz can be found in (Entesari & Rebeiz, 2005 a), the design uses metal air metal capacitors, and MEMS capacitive switches to reconfigure its center frequency.

3.2. Tunable filters using MEMS varactors

The use of MEMS varactors can result in low filter insertion losses, and are used to provide a continuous filter parameter reconfiguration. MEMS varactors are suitable for miniature lumped element filters due to the high quality factor presented by the MEMS varactors, compared with conventional components like the metal insulator metal capacitor. MEMS varactors can also be used to load distributed resonators to achieve tunable filters. This section discusses filters made with bridge type and cantilever type MEMS varactors, where several filter topologies are described.

3.2.1. Filters using bridge type varactors

Filters that use MEMS varactors formed by bridge type actuators, can reconfigure filter parameters in a continuous fashion. The actuators are fixed on both ends, and are actuated using a bias voltage between the bridge and actuation electrodes, which will control the variable capacitance. This section discusses filters made using bridge type MEMS varactors on distributed and lumped topologies as well as a design based on periodic structures.

3.2.1.1. Distributed designs

In (Abbaspour-Tamijani et al., 2003) bridge type MEMS varactors are used to load coplanar transmission line resonators in order to achieve a reconfigurable center frequency. Fig. 9 shows the fabricated filter and the tunable center frequency response for different bias voltages supplied to bridge type varactors. The filters in (Mercier et al., 2004) use bridge varactors to adjust all filter design parameters at millimeter waves.

3.2.1.2. Lumped element designs

The filters in (Kim et al., 2002) use MEMS bridge varactors to tune V-band bandpass filters using compact lumped element filter designs. Other lumped element filter using spiral inductors and metal air metal capacitors can be found in (Kim et al., 2005), where bridge MEMS capacitors are used to tune center frequency at K-band.

3.2.1.3. Filters using periodic structures

A tunable bandstop filter designed using an electromagnetic bandgap periodic structure has been reported in (Karim et al., 2005), where MEMS bridge type varactors have been used in between the bandgap cells to tune the filter response.

3.2.2. Filters using cantilever type varactors

This section contains filters using cantilever type MEMS varactors as tuning elements, these elements have been used to produce a continuous filter parameter reconfiguration by modifying the capacitance between a movable cantilever and a fixed metallic plate beneath it. The capacitance changes according to a bias voltage applied between the cantilever and an actuation electrode, the bias voltage causes cantilever displacement thus forming the variable capacitance. This section discusses distributed and a lumped element design.

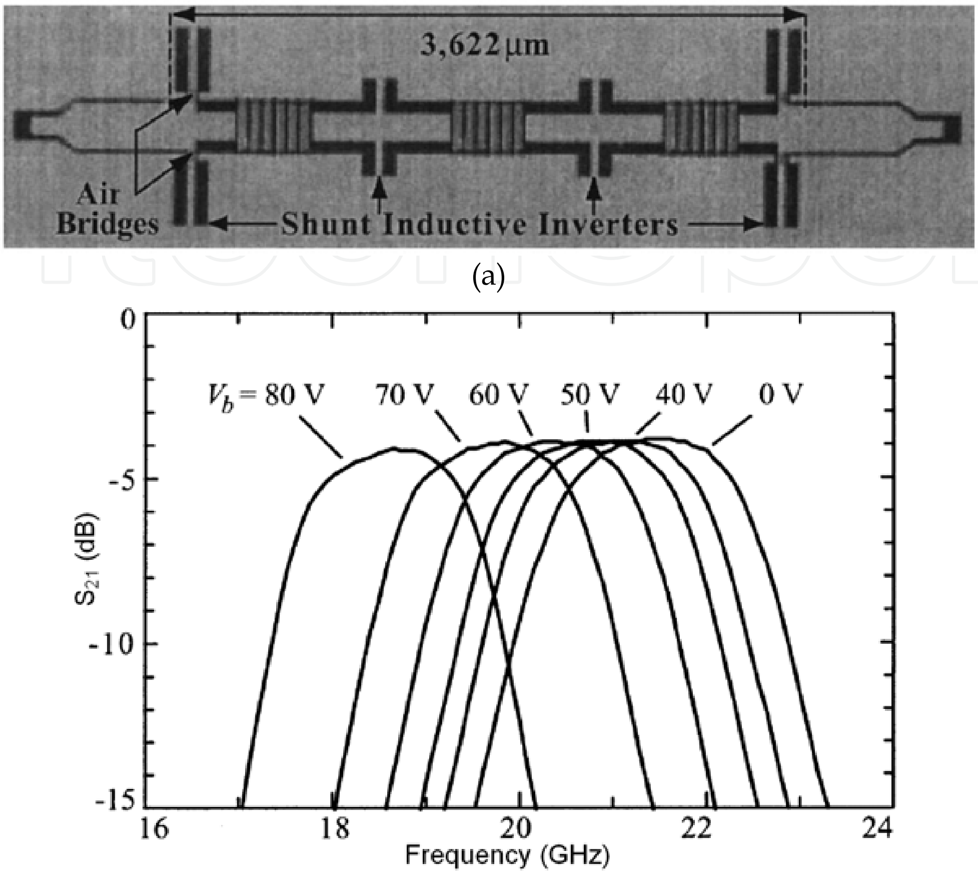

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Fig. 9. Tunable bandpass filter using MEMS varactors a) photography of the fabricated filter b) filter response, taken from (Abbaspour-Tamijani et al., 2003)

3.2.2.1. Distributed designs

The device in (Fourn et al., 2003 b) uses MEMS cantilever type varactors to achieve center frequency and bandwidth tuning at Ka-band, the filter topology is based on dual behavior resonators, the device has two poles, and the MEMS varactors were placed at the ends of the proposed resonators. One of the filters in (Kim et al., 1999) uses MEMS cantilever varactors to modify the resonant frequency of distributed resonators on a bandpass filter topology at Ka-band. The slot resonator tunable bandstop filter in (Yan & Mansour, 2007 b) uses a thermal actuator as a tuning plate to produce a reconfigurable center frequency at around 6 GHz.

3.2.2.2. Lumped element designs

A lumped element tunable filter at Ka-band has been reported in (Kim et al., 1999), the device can reconfigure its center frequency according to bias voltages applied to a MEMS cantilever varactor.

4. Tunable filters using ferroelectric materials

Ferroelectric materials can change permittivity values proportionally to an applied DC electric field where some ferroelectrics are suitable for thin film deposition. This section focuses on tunable microwave filters using three of the most common ferroelectrics used to date, the Barium-Strontium-Titanate oxide (BST), the Strontium-Titanate Oxide (STO), and the lead Strontium-Titanate oxide (PST). Other ferroelectric materials considered for microwave tunable devices are the sodium potassium niobium oxide or the bismuth zinc niobate oxide ferroelectric which are not covered in this section. Ferroelectrics have been very attractive due to their compatibility with planar microwave electronics and technologies to produce high speed reconfigurable devices.

4.1 BST

A tunable quasi-elliptic bandpass filter using BST capacitors located on open loop ring resonators can be found in (Courreges et al., 2009), the filter topology and its tunable bandpass response is shown in Fig. 10.

The two pole bandpass filter using slow wave coplanar resonators in (Papapolymerou et al., 2006) can tune its center frequency by capacitive loading the resonators with ferroelectric varactor banks; the device can tune its center frequency from 11.5 to 14 GHz. The three pole combline filter in (Nath et al., 2005) uses ferroelectric varactos at one end of the resonators to produce a tunable center frequency from 2.44 to 2.88 GHz with good impedance matching for all states and a 400 MHz bandwidth.

A tunable bandstop filter using slotted ground resonators has been reported in (Chun et al., 2008 a), the device can tune its stopband bandwidth from 1.2 to 1.4 GHz. The lumped element tunable filter in (Sanderson et al., 2007) was designed to tune its center frequency from 31.5 MHz to 88 MHz with a 3 MHz bandwidth; the device uses 8 ferroelectric varactors.

4.2. STO

The tunable filter in (Subramanyam et al., 1998) uses a STO thin film to tune its center frequency, the permittivity of the ferroelectric film changes with temperature as well as with an applied bias voltage. The center frequency tuning range is from 18.3 to 19.15 GHz with a 4% fractional bandwidth.

4.3. PST

The filter in (Chun et al., 2008 b) uses high resistivity silicon as a substrate with integrated ferroelectric capacitors; this structure has been used to make a tunable resonator and a bandstop filter. The resonator and filter topology are based on a slotted coplanar resonator, and the device can tune its center frequency from 3.65 GHz to 4.23 GHz.

5. Tunable filters using ferromagnetic materials

Tunable filters using ferromagnetic materials like Yttrium-Iron-Garnet (YIG) results in high unloaded quality factor resonators with high power handling capabilities and high power consumption. Resonators using YIG spheres have been traditionally used (Carter, 1961), despite the high unloaded quality factors obtained, the filters require very precise fabrication involving high costs, and also other drawbacks are a low tuning speed and a complex tuning mechanism involving coils near the spheres.

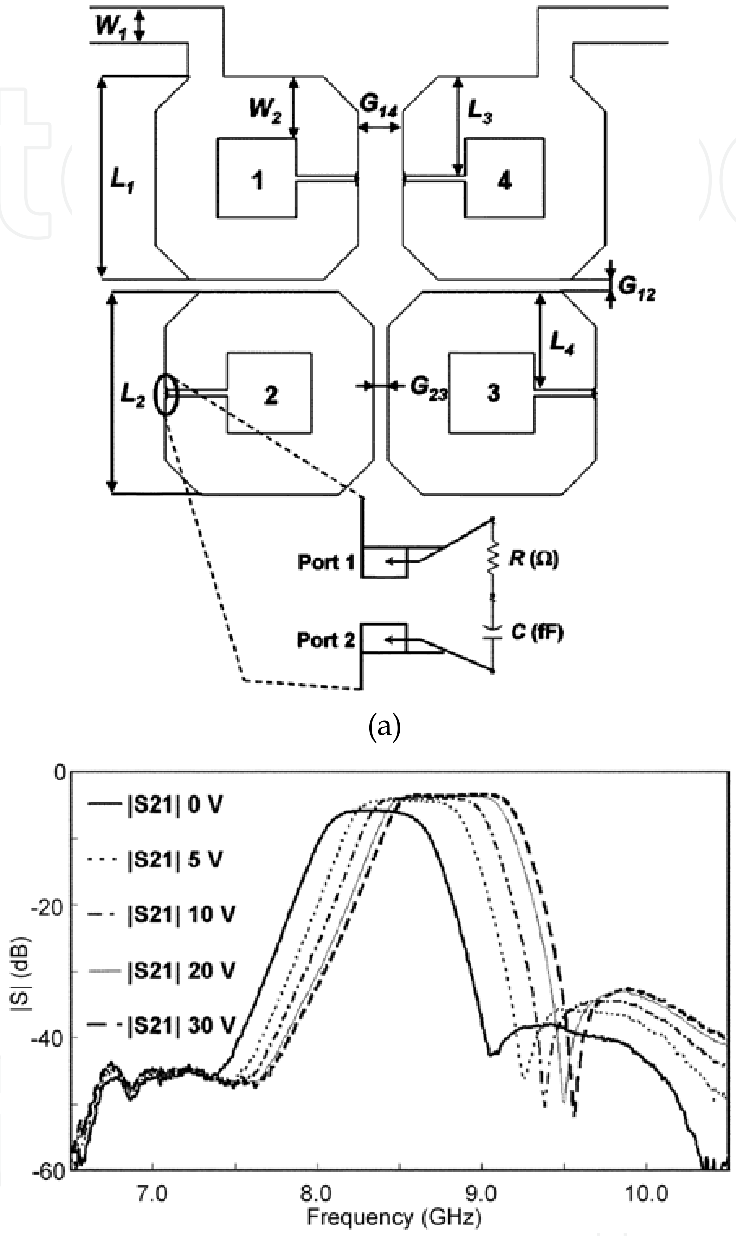

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Fig. 10. Tunable bandpass filter using ferroelectric varactors a) topology b) filter response, taken from (Courreges et al., 2009)

This section discusses tunable filters using ferromagnetic materials in planar forms, which present ease of fabrication and integration with planar transmission lines or bias mechanisms. The section is divided in two, the first part deals with tunable filters using YIGs and the second part focuses on designs based on other ferromagnetic tuning structures.

5.1. Yttrium-Iron-Garnet films (YIG)

The device in (Murakami et al., 1987) uses a YIG film in a two pole filter topology, the design has a 16 MHz bandwidth and can tune its center frequency from 0.5 to 4 GHz. Fig. 11 contains the structure used for this filter, as well as its frequency response.

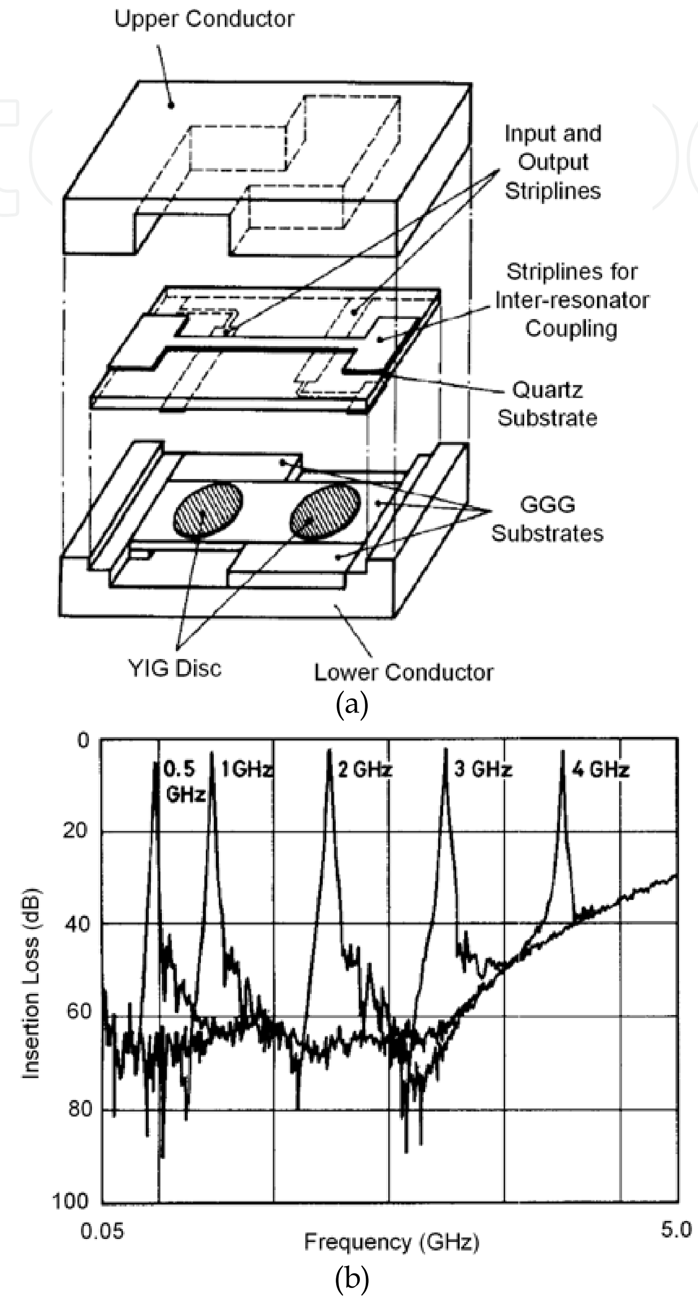

Fig. 11. Tunable bandpass filter using ferromagnetic disks a) filter structure b) filter response, taken from (Murakami et al., 1987)

The filters in (Tsai & Qiu, 2009) use a gallium arsenide substrate and ferromagnetic resonance tuning, bandstop and bandpass topologies are demonstrated, the bandpass filter can tune its center frequency from 5.9 to 17.8 GHz. These devices have wide tuning ranges, good power handling and tuning speed capabilities.

A single cavity resonator using ferromagnetic resonance has been reported in (Srinivasan et al., 2005), the proposed resonator uses ferrite-ferroelectric layers; the cavity design is tuned by magnetoelectric interactions between the layers used to form the resonator. A bandpass filter based on ferromagnetic resonance using piezoelectric-YIG layers has been reported in (Tatarenko et al., 2006), where a device is demonstrated with a tuning range from 6.65 to 6.77 GHz.

5.2. Other ferromagnetic tuning based devices

The tunable banstop filter in (Tsai et al., 1999) uses an iron film over a gallium arsenide substrate. The filter has a large tuning range from about 10 to 27 GHz, this device has been tuned at higher frequencies than the devices presented in previous section. In (Salahun et al., 2002), a laminated ferromagnetic and insulator composite material has been used to tune a pair of resonators, a stub resonator exhibited a frequency tuning range from 1.17 to 1.71 GHz.

6. Tunable filters using combined technologies

This section discusses devices that combine different technologies to achieve reconfigurable filtering. The section describes filters that combine ferroelectric materials with either MEMS or active devices, and ends with a reconfigurable dielectric resonator filter using MEMS tuning elements.

6.1. Tunable filters using ferroelectric varactors and transistors

The negative resistance technique using a commercial transistor has been used to compensate ferroelectric and circuit losses in (Kim & Park, 2007). The filter topology is made out of commercial lumped elements and ferroelectric capacitors on a high resistivity silicon substrate. The bandpass device has two poles with a 110 MHz bandwidth and a center frequency tuning range from 1.81 to 2.04 GHz.

6.2. Tunable filters using ferroelectric varactors and MEMS switches

A combination of BST varactors for center frequency tuning and cantilever direct contact MEMS switches for bandwidth tuning is presented in (Lugo et al., 2007); the filters can provide wide and narrow bandwidth configurations on two and three pole topologies. The continuous tunable center frequency goes from 30 to 35 GHz.

6.3. Tunable filters using dielectric resonators and MEMS actuators

A tunable bandpass filter using high unloaded quality factor dielectric resonators has been reported (Yan & Mansour, 2007 a), the device is tuned using MEMS thermal actuators with large deflections to tune center frequency. Fig. 12 contains a schematic of the tunable structure, a view of a MEMS actuator and filter response.

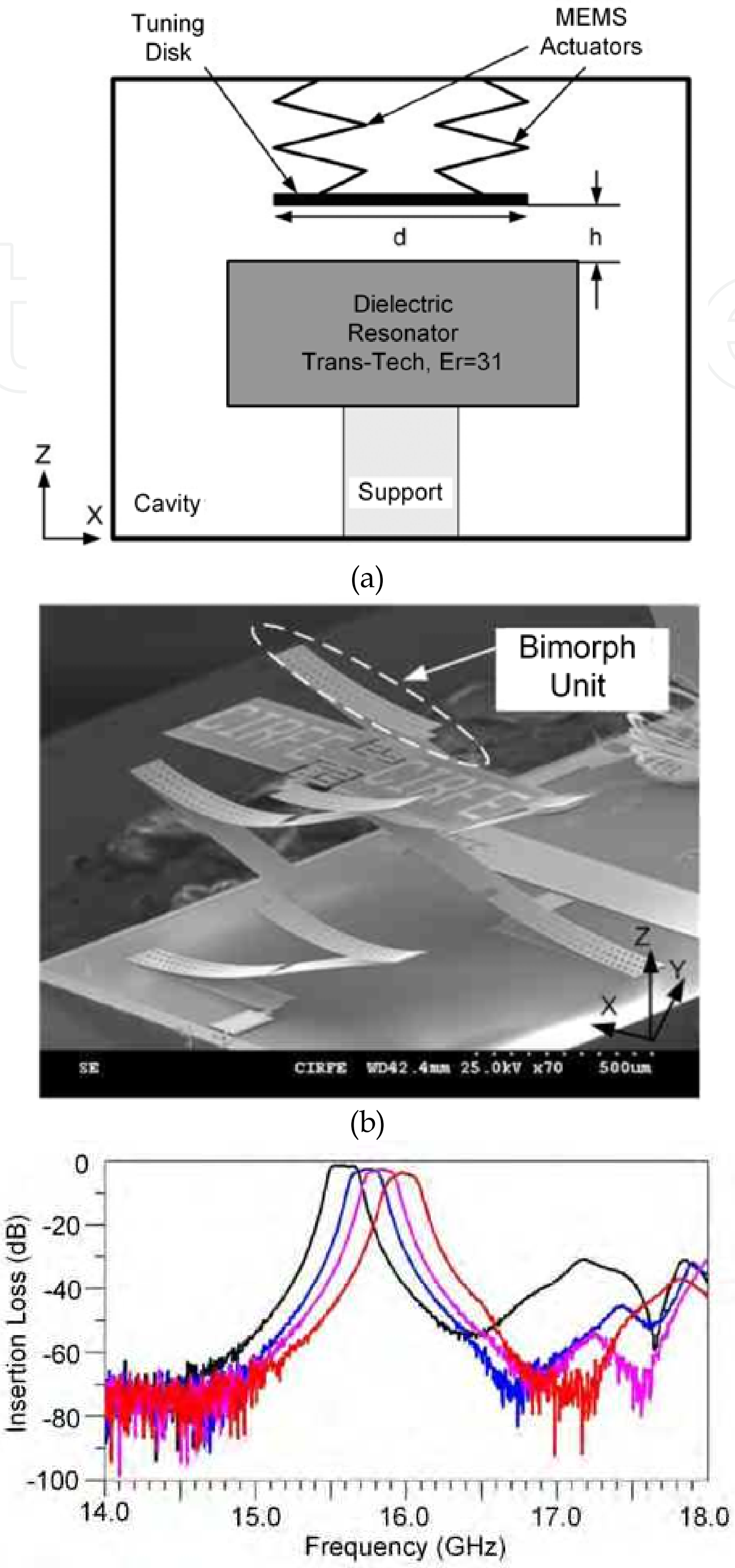

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Fig. 12. Tunable bandpass filter using dielectric resonators and MEMS thermal actuators a) tuning structure schematic b) MEMS thermal actuator isotropic view c) filter response, taken from (Yan & Mansour, 2007 a)

7. Mechanically tuned filters

Mechanically adjustable dielectric or metallic tuning screws are commonly used to tune microwave filters. These techniques are frequently used to compensate fabrication tolerances, where the screws can be moved manually while monitoring the measured response. Automated tuning programs can automatically find an optimum filter response by iterating tuning screw positions until a user defined response is found.

The tuning screws can be placed strategically on top or near microwave resonators to tune the resonant frequency of individual resonators. The screws can be placed between resonators to modify inter-resonator coupling coefficients, or screws can be placed between the input/output coupling structure to the filter and the first/last resonator to adjust the input and output coupling to the filter.

Also the type of screw is important depending on the electric and magnetic field distribution near the resonator to be tuned; in general, dielectric tuning screws are mostly used where the electric field maximums around the resonator can be found. Similarly metallic tuning screws are mostly used where magnetic field maximums around the resonator are found.

8. Conclusions

This chapter presented diverse methods for tuning microwave filters with the objective of providing an overall view of the field. The filters discussed in this chapter were classified by the technology used to tune filter parameters. Some devices are miniature type lumped element filters and others involve distributed designs with larger size but higher resonator unloaded quality factors in general. The chapter covered filters made using different technologies including active devices, MEMS, ferroelectric and ferromagnetic materials. Filters involving combined technologies were covered; and also the traditional tuning using mechanically adjustable screws was discussed. In this section a general technology summary is provided, pointing out some important features and drawbacks associated with each technology.

Microwave tunable filters can reconfigure filter parameters like center frequency, bandwidth or selectivity in a discrete or continuous fashion, according to the tuning element used to reconfigure the given filter parameter.

One important issue to look at is the operating frequency range of the filters according to the technology used for its fabrication. Diode tuned filters have been used at design frequencies ranging from VHF to X band (0.03 – 12.4 GHz). Filters made using MEMS technology have high potential of operating at much higher frequencies compared to diodes, for instance filter designs can be found with an operating frequency range from VHF to U band (0.03 – 60 GHz). Capacitive MEMS tuning elements have been used for high frequency operation, and direct contact type MEMS actuators are normally used for low frequency operation. Ferroelectric tuned filters have been mainly focused on operating frequency ranges from VHF to K band (0.03 – 26.5 GHz) where some few designs have center frequencies up to U band (60 GHz). Ferromagnetic tuned filters have been used in general for operating frequencies up to K-band.

Diodes have the advantage of being most of times a low cost tuning technology, where also fully monolithic designs can present the possibility of high integration with other components on a single chip, or a System On Chip (SOP) approach. Also surface mount diodes can be used on microwave substrates, for a System On Package (SOC) approach. Diodes produce inter-modulation noise due to their intrinsic non linear response, and consume higher power compared to their MEMS counterpart.

RF MEMS devices have a small size and good integration capability and superior performance compared to diodes. RF MEMS have good compatibility with fabrication technologies used in semiconductor industries and have good performance in terms of losses and noise. MEMS devices consume very low currents resulting in low power consumption compared to using diodes as tuning elements. Currently the main drawback of MEMS tunable filters is related to reliability issues of the MEMS tuning elements, where the MEMS switches or varactors are frequently associated with life cycles before a MEMS tuning element break down. Also dielectric charging produces unwanted stiction effects degrading the MEMS tuning element reliability. Many efforts have been made to improve MEMS tuning reliability where hermetic packages have resulted in improved life cycles, however more effort to overcome this reliability limitation must be carried out before MEMS tuning elements can make it to successful commercialization.

Tunable filters that use ferroelectric materials as tuning elements have a good integration advantage due to thin film ferroelectric material deposition; suitable for highly integrated microwave devices compatible with planar circuits, with high tuning speeds. Ferroelectric materials have the main disadvantage of having a high loss tangent associated to them, and hence low resonator unloaded quality factors are generally related to resonators with embedded ferroelectric materials. In general a high permittivity tuning range on a ferroelectric material is associated with a high loss. A continuous effort is carried out to obtain a ferroelectric material with low loss tangent and high permittivity tuning range; this still is a challenge today.

Tunable filters that use ferromagnetic materials as tuning element like YIG tuned resonators, have a main advantage of having high unloaded quality factor resonators for the filter design. Other advantage is that the resonant frequency of the YIG crystals does not depend on the length of the resonators, and results in a circuit with compact tunable high unloaded quality factor fixed size resonators, which can be tuned over a large frequency range. The main drawbacks of ferromagnetic tuned filters is a complex bias circuit to tune the device with high power consumption, also a low tuning speed is generally associated with many of these devices.

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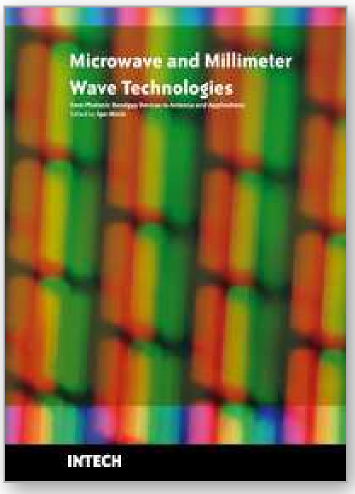

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The book deals with modern developments in microwave and millimeter wave technologies, presenting a wide selection of different topics within this interesting area. From a description of the evolution of technological processes for the design of passive functions in milimetre-wave frequency range, to different applications and different materials evaluation, the book offers an extensive view of the current trends in the field. Hopefully the book will attract more interest in microwave and millimeter wave technologies and simulate new ideas on this fascinating subject.

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