Quasi-Lumped Element Suspended Stripline Filters for Integration into Microstrip Circuits

Wolfgang Menzel, Mohammad S. Tito, Guangwen Qu

Abstract — **A novel concept is presented to incorporate suspended stripline (SSL) filters into extended microstrip circuits. To this end, the filters are designed with integrated transitions to microstrip. The necessary channel for suspended stripline is formed by a grove in the carrier plate and a small cap above the filter; the two parts of the channel are connected by rows of vias. Different types of filters are presented to prove the concept, together with a four channel multiplexer consisting of branch line couplers and SSL filters.**

Keywords — **Filters, low-pass filters, band-pass filters, high-pass filters, multiplexers, stripline filters, lumped element circuits, integrated planar circuits.**

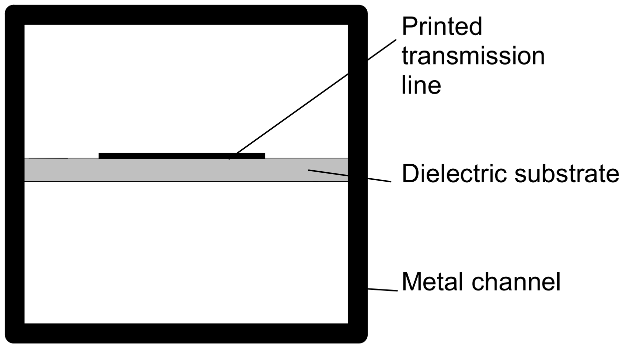

Fig. 1: Basic cross section of a suspended stripline

I. Introduction

Suspended stripline (SSL) consists of transmission line structures printed on a substrate suspended in a shielding channel (Fig. 1). An increased cross section together with a relative thin substrate are responsible for reduced ohmic and dielectric losses. The shielding channel prevents radiation, and, if sufficiently small, the excitation of higher order modes. A large portion of the fields in air results in low dispersion of the SSL. With these properties, SSL has proven as an interesting medium for all types of filters. Both transmission line filters, e.g. [1], as well as quasi-lumped filters, e.g. [2 - 5], have been realized in this technique. Arranging the filter elements on both sides of the substrate provides enhanced degrees of freedom for circuit design including improved coupling between filter elements or the seamless integration of further circuit structures to add transmission zeros, for example [3, 4]. SSL allows the realization of all types of lumped elements – a patch-like structure gives a shunt capacitance, a thin strip either in series or to the metal shielding at the side gives a series or shunt inductance, respectively, and end coupling (including overlapping or interdigital structures) provides series capacitances [5].

A potential drawback with respect to integration of such filters into larger circuits, however, is due to the necessity of the shielding channel and the fact that SSL is a transmission line medium not readily compatible with standard integrated circuits. Therefore, up to now, such filters were mostly realized as discrete components with coaxial connectors, making a seamless integration into more complex circuits difficult. This paper describes a possible solution and presents examples of filters with microstrip interconnects, together with an integrated four channel multiplexer circuit consisting of eight SSL filters and eight microstrip branch line couplers with defected ground plane to allow a sufficiently wide bandwidth of the couplers.

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II. SSL Filters for Integration into Microstrip Circuits

For an integration into larger circuits which often contain microstrip circuits, at least the following conditions must be met:

- Small size of the filters
- No special form of the substrate, no cut-outs
- No extended metal mount
- Microstrip connections of the filters to the external circuit

To this end, quasi-lumped element filters as described in [2 - 5] form the basis of this approach. Secondly, these SSL filters include a compact and integrated transition from SSL to microstrip. Consequently, the necessary SSL channel is required only in the area of a filter itself and can be realized, on the one hand, by a grove under the SSL portion of the filter in the carrier block of the circuit, and on the other hand, by fixing a small cap on top of the SSL filter (Fig. 2). The conductive connection between carrier block and cap is done by rows of vias along the edges of the filter channel [6]. Using substrates like RO4003, such vias can be fabricated easily using conventional printed circuit board (PCB) technology. In this way, no cutting of the substrate to the special form of a SSL filter is necessary.

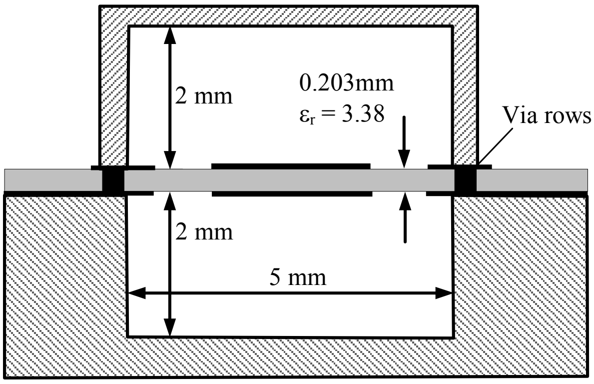

Fig. 2: Cross section of suspended stripline with extended substrate and vias to connect top and bottom portion of the mount. Typical dimensions for most of the filters presented in this paper are given in the figure.

The design of the filters presented in this work is done as described in detail in [5]. The cross section for the 2½D simulation [7] of the filters is that of an ideal structure as indicated in Fig. 1, the cross section for the final realization that of Fig. 2. As the vias need some metal rim around them, small strips of metal are already taken into account in the simulation setup. At the same time, such metal strips reduce the tolerances requirements of the substrate position in the mount; if some metallization comes closer to the channel wall, the capacitance is mostly determined by the field towards these strips.

To characterize single filters, a test mount was built consisting of a carrier plate with the grove and a metal cap. A photograph of this test-setup is shown in Fig. 3 – the mount itself, the opened mount with a test filter in place, and the closed filter configuration. In a practical realization, the lengths of grove and cap are adjusted to the actual filter size. The filters are characterized experimentally using on-wafer probing (with vias to provide ground connections on the top side of the substrate) together with a TRL calibration.

III. Filter Examples

The concept as described above was tested at a number of SSL filters shown in the following. The first filter is a five-element lowpass filter. The inductive elements are formed by thin series strips and the capacitive elements by patches, reduced in size by placing a ground plane below them. In addition, this filter includes further elements to generate transmission zeroes. To this end, the edges of the capacitive patches are brought close together, and small metal sections are placed on the backside forming additional coupling capacitances in parallel to the inductive elements (see Fig. 4, top and center), resulting in two transmission zeroes of the lowpass filter [4]. The transmission behavior of this filter is shown in Fig. 4, bottom. This filter is displayed as example filter in the photograph of Fig. 2. Simulation and experiment agree very well; insertion loss is a few tenths of a dB. Filter length is 7.1 mm only, so in a respective circuit, a much shorter grove and cap compared to the test setup can be used.

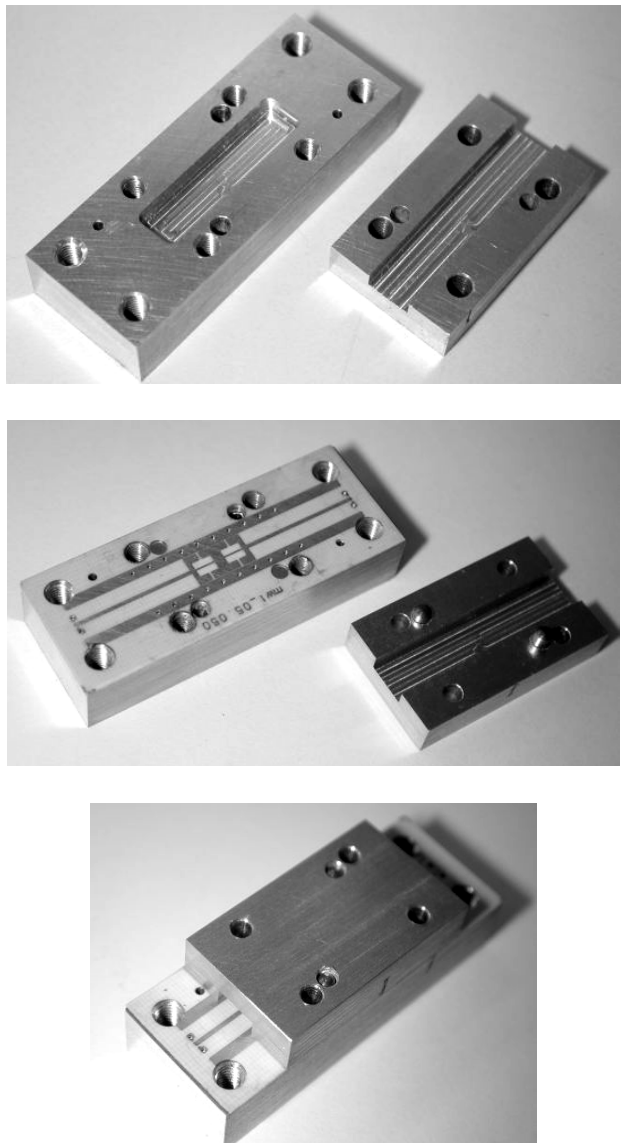

Fig. 3: Photograph of the empty test mount (top) and a lowpass filter on extended substrate in the test mount. Center: opened block with filter, bottom: assembled test setup.

The second example is a three-resonator bandpass filter. Capacitively coupled shunt resonators consist of a patch and a metal strip to ground (at the side of the channel); some inset increases the inductance. Input and output include transitions to microstrip which, during the design of the filter, have been handled as integral part of the outer inverters. Equivalent circuit and layout of both sides of the substrate, together with simulated and experimental performance are presented in Fig. 5. The length of this filter is 11.4 mm. Passband insertion loss is between 0.4 dB and 0.65 dB. Compared to a standard coupled transmission line filter, the stopband width of this quasi-lumped approach is increased considerably.

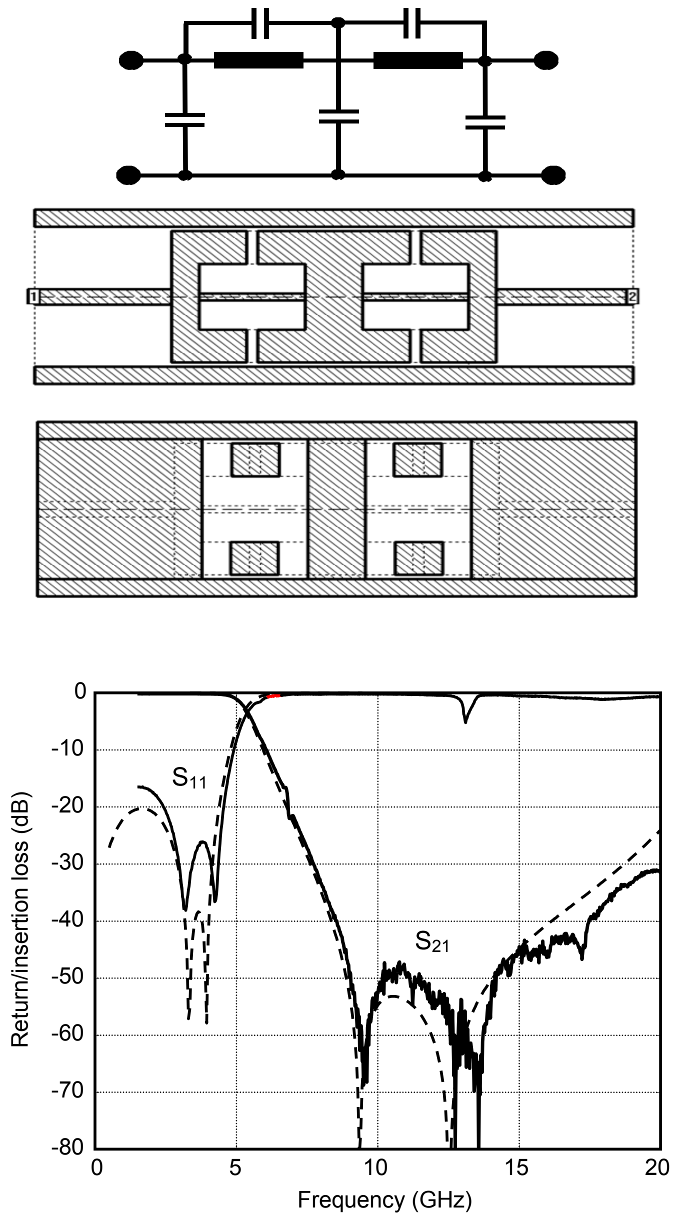

Fig. 4: Equivalent circuit, top and bottom side layout (top and center), and filter characteristics (bottom) of a five element lowpass filter with microstrip input and output lines. Dashed lines: simulation, solid lines: experiment.

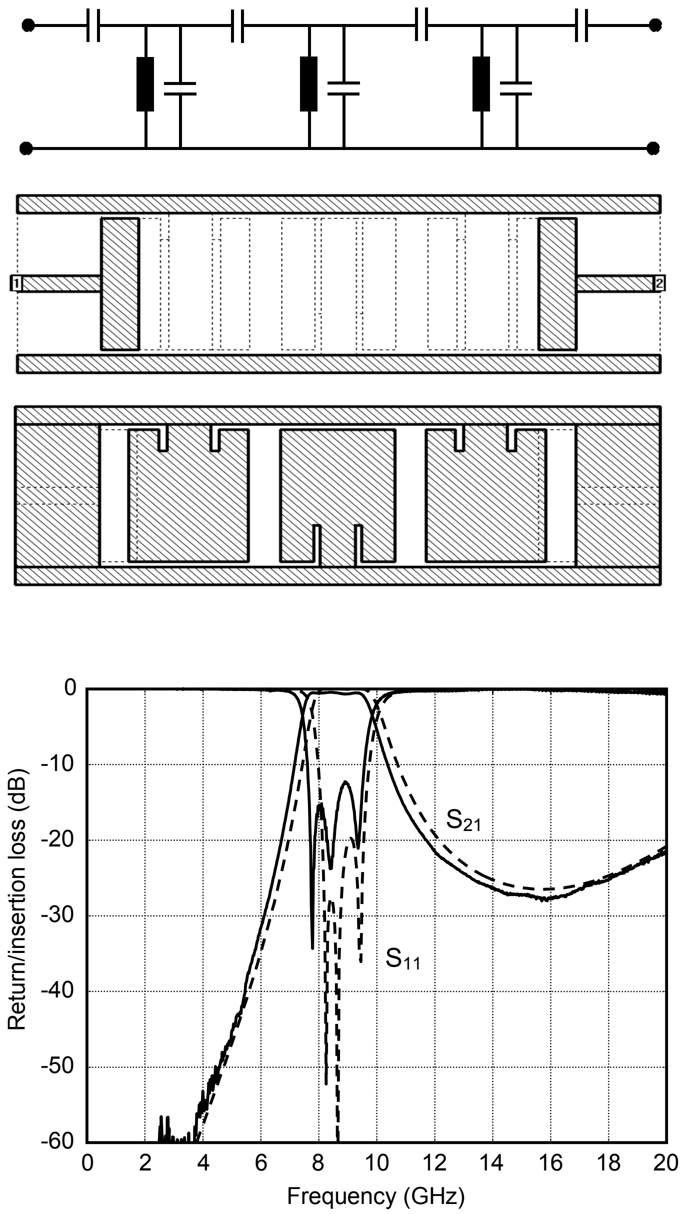

Fig. 5: Equivalent circuit, top and bottom side layout (top and center), and filter characteristics (bottom) of a three-resonator bandpass filter with microstrip input and output lines. Dashed lines: simulation, solid lines: experiment.

Next, a highpass filter with very wide passband from 6 GHz to 20 GHz is presented. By overlapping metallizations, very high coupling capacitances are realized, while the patch capacitances to ground (Fig. 6, top and center) play only a minor role. An approximate equivalent circuit, filter layout and results are displayed in Fig. 6. Filter length is 12.8 mm. Between 5.5 GHz and 20 GHz, measured return loss is better than -10 dB; insertion loss is a few tenths of a dB in this frequency range.

As a last single filter example, an UWB filter is presented consisting of the combination of a seven-element lowpass filter and a three-element highpass filter. The highpass filter has a similar structure like that of the previous example. In addition to such an UWB filter as reported previously [9], this one once again includes transitions to microstrip and thus is easily integrated into an extended microstrip circuit. A photograph of the filter is shown in Fig. 7; layout of top and bottom side of the substrate as well as return and insertion loss are given in Fig. 8. The length of the filter is 11.6 mm. Passband insertion loss is between 0.2 dB and 0.5 dB. Experimental group delay is plotted in Fig. 9, its variation amounts to maximally 0.15 ns within the passband. Due to small imperfections in the calibration process, the differentiation of the phase of S21 led to some noisy behavior of the curve.

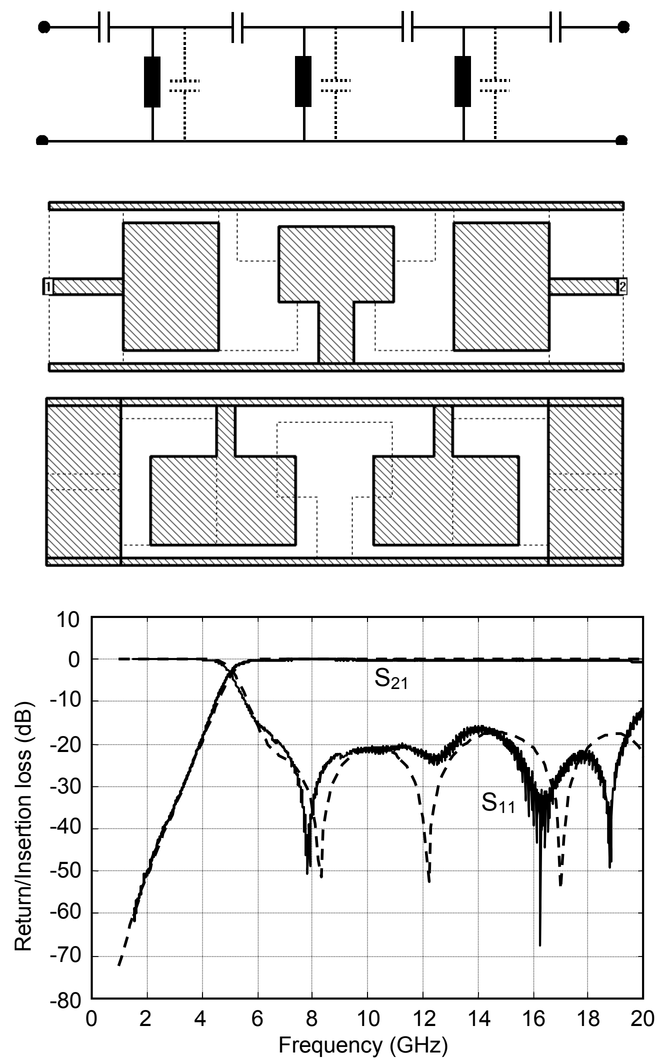

Fig. 6: Equivalent circuit, top and bottom side layout (top and center), and transmission characteristics (bottom) of a seven element highpass filter with microstrip input and output lines. Dashed lines: simulation, solid lines: experiment.

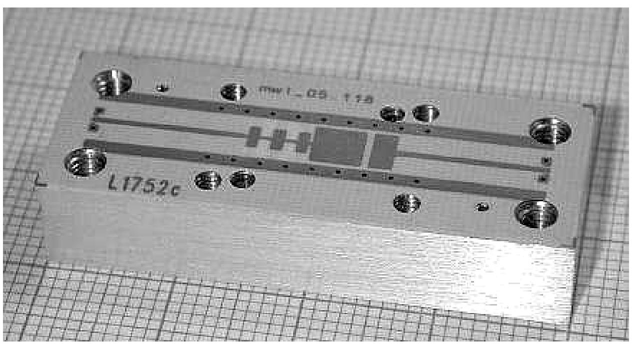

Fig. 7: Photograph of an UWB filter with microstrip input and output lines.

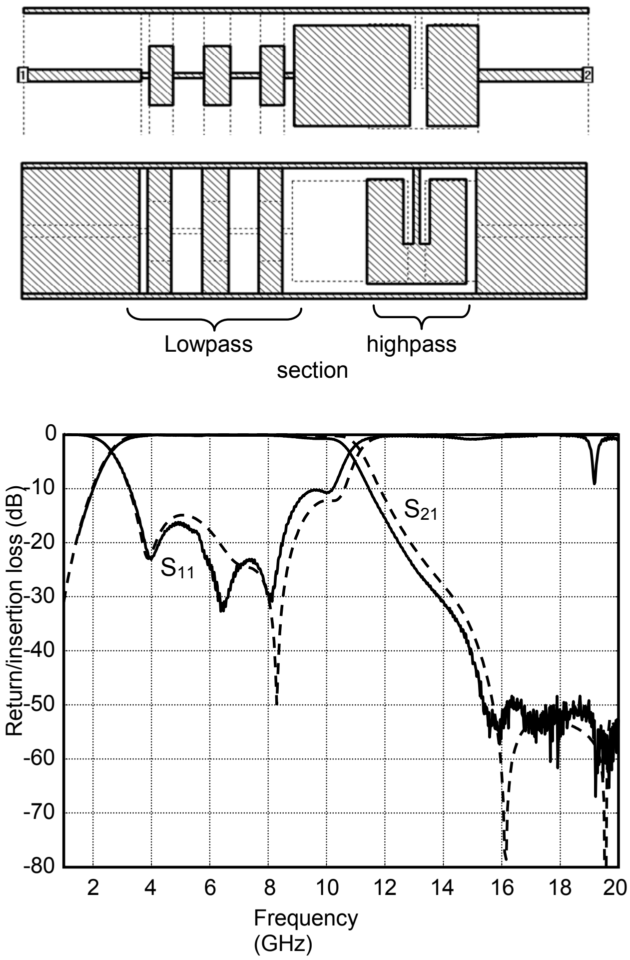

Fig. 8: Top and bottom side layout (top) and filter characteristics (bottom) of a UWB filter with microstrip input and output lines consisting of a combination of lowpass and highpass filters. Dashed lines: simulation, solid lines: experiment.

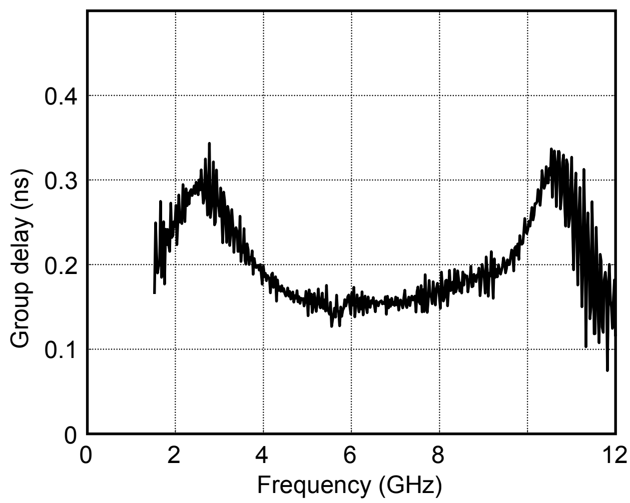

Fig. 9: Experimental group delay of the UWB filter.

IV. Integrated Multiplexer

As an example for a more complex arrangement, a hybrid coupled multiplexer demonstrates the integration of eight SSL filters and branch line couplers each. A frequency band from 8 GHz to 12 GHz is separated into 4 bands, each 1 GHz wide. The basic block diagram of the multiplexer is shown in Fig. 10 ([10, 11]. The broadband incident signal is feed to port 1 and passes the two branches of the first input coupler. The frequency portion between 11 GHz and 12 GHz is transmitted through the filters and the first output coupler and is combined at port 2. Other frequencies are reflected at the filters, combined at port b (Fig. 10), and fed to the next filter pair. In this way, all frequencies within the desired bands are selected and appear at the respective output ports. As the couplers have to provide a bandwidth of 40%, a four-branch design according to [12] was chosen. While the main lines are standard 50 Ω microstrip lines, the branches were realized as modified microstrip lines with defected ground plane and groves in the carrier block to cope with the required, rather high characteristic impedances (nearly 140 Ω for the two central branches). The four pairs of filters are SSL bandpass filters similar to that described above and shown in Fig. 5. Each coupler exhibits losses of about 1 dB. The SSL filters have five resonator each, but they were not optimized for minimum loss, so losses between 1.2 dB and 1.5 dB are due to the filters. Nevertheless, losses are considerably lower than those of pure microstrip filters. The filters for the highest frequency (and therefore with the highest losses) are placed closest to the multiplexer input. According to the increasing path length with decreasing frequency, the lower frequency path loss is higher (Fig. 12). Nevertheless, such a structure provides a highly integrated multiplier arrangement and clearly demonstrates the integration method as described in this paper.

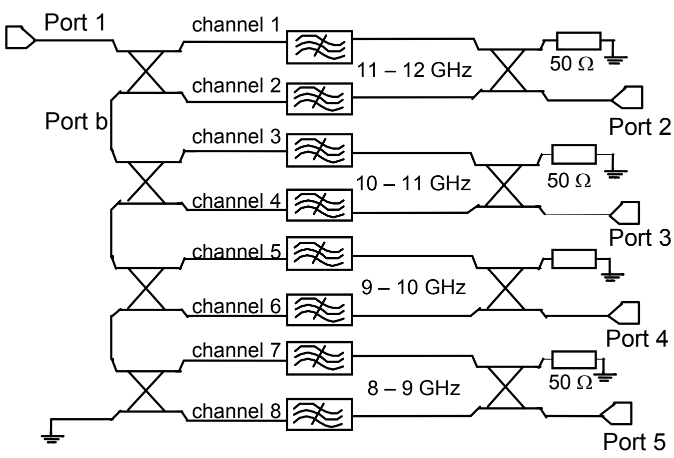

Fig. 10: Block diagram of the four channel multiplexer.

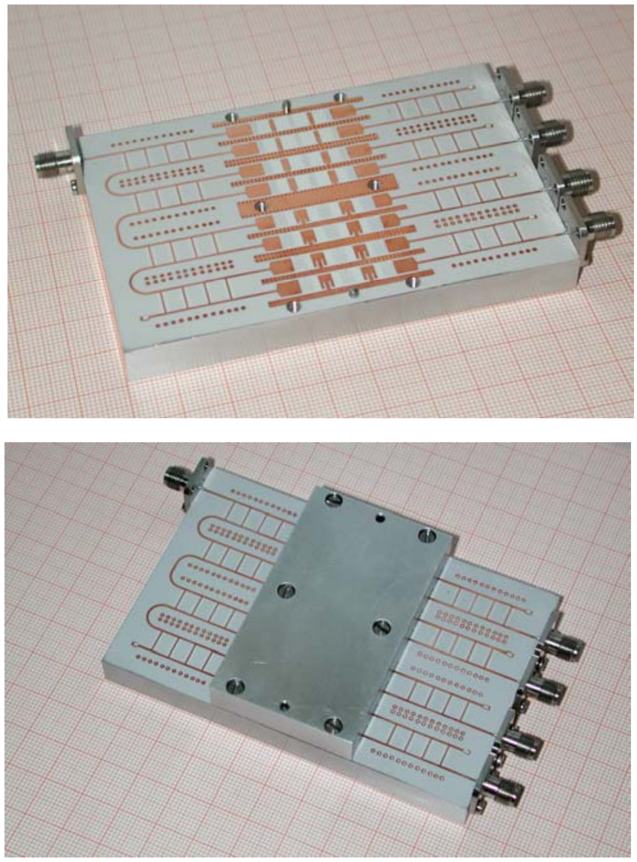

Fig. 11: Photographs of the four channel multiplexer without and with channel cap in place.

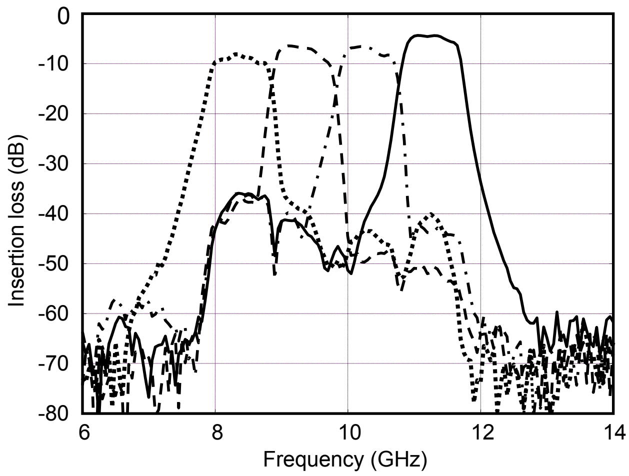

Fig. 12: Transmission behavior of the four channel multiplexer.

V. Conclusion

This contribution has demonstrated a method to integrated suspended stripline filters into extended microstrip circuits. In this way, the high degree of integration of microstrip circuits can be combined with the reduced loss of the SSL filters. Due to the filter realization with quasi-lumped elements, these filters exhibit, at the same time, a reasonably small size. Four different example filters have been presented to prove the concept for the filters, together with a four channel multiplexer .

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