LPKF ProtoLaser U4 – Application Report

A comparison of different production methods

Laser & Electronics

ProtoLaser U4 vs. ProtoMat S103 vs. classical etching

Using three different methods, a circuit board prototype of a microstrip bandpass filter is produced and the results are compared. In the first two methods, the circuit board is structured by mechanically removing the copper from the base material once by laser ablation (ProtoLaser U4) and second by milling (ProtoMat S103). The third method is the classical chemical method of etching the copper. It is also the comparison between the fast and simple in-house procedures laser ablation and milling compared to the classic printed circuit board production technique.

Structure of the filter

Two bandpass filters were investigated for frequencies of 2.4 GHz and 10 GHz. The filters were each made from two basic materials. On the one hand, the inexpensive standard FR4 material of thickness 1.0 mm with 18 µm copper coating. On the other hand, the special low-cost Rogers RO4003C high-frequency material of 0.81 mm thickness. The circuit characteristics were simulated with the simulation software CST and the determined S-parameters were used as reference values.

Figure 1: CAD-design of 2.4 GHz bandpass filter for basic material Rogers RO4003C

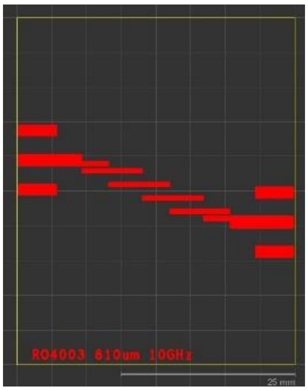

Figure 2: CAD-design of 10 GHz bandpass filter for basic material Rogers RO4003C

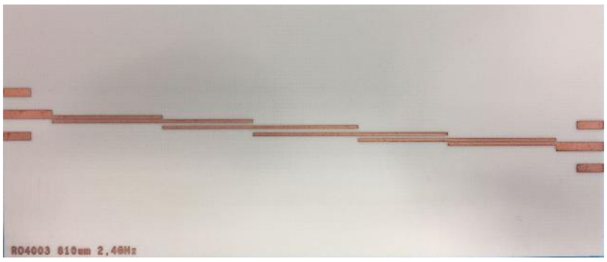

Figure 3: Circuit board of 2.4 GHz bandpass filters made from basic material Rogers RO4003C

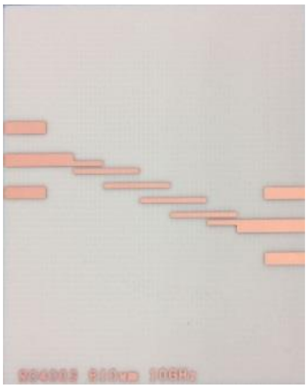

Figure 4: Circuit board of 10 GHz bandpass filter made from basic material Rogers RO4003C

The measurements

The mechanical dimensions of the boards were determined with an optical measuring system. The RF transmission parameters (scattering parameters) were analyzed at the Fraunhofer Institute IAF using a network analyzer (PNA-E8361C) from Agilent.

Results

The measured lengths and widths of the circuit boards produced in the laser ablation, milling and etching production processes as well as the values provided in the CAD data are listed in tables 1 to 4.

In every manufacturing technology, the final geometry of the circuit boards is influenced by various factors. In the case of chemical etching, the transfer of the layout film to the base material as well as under- or over-etching plays a major role. The optimal calculation of toolpaths, tool parameters and absorption is crucial in laser processing. In mechanical milling, the adhesion between copper and substrate is important in addition to the tool path calculation as well as the sharpness and geometry of the milling tools used.

Technolo-gy	CAD values		Measured values	
	x [mm]	y [mm]	x [mm]	y [mm]
Laser	38.2	0.6	38.261	0.598
Etching	38.2	0,6	37.729	0.566
Milling	38.2	0.6	38.167	0.622

Table 1: Circuit board dimensions of bandpass filter 2.4 GHz, base smaterial Rogers RO4003C

Technolo-gy	CAD values		Measured values	
	x [mm]	y [mm]	x [mm]	y [mm]
Laser	35.4	0.6	35.400	0.604
Etching	35.4	0.6	35.425	0.573
Milling	35.4	0.6	35.405	0.605

Table 2: Circuit board dimensions of bandpass filter 2.4 GHz, basic material FR4

Technolo-gy	CAD values		Measured values	
	x [mm]	y [mm]	x [mm]	y [mm]
Laser	8.8	0.7	8.718	0.688
Etching	8.8	0,7	8.805	0.678
Milling	8.8	0.7	8.764	0.650

Table 3: Circuit board dimensions of bandpass filter 10 GHz, base material Rogers RO4003

Technolo-gy	CAD values		Measured values	
	x [mm]	y [mm]	x [mm]	y [mm]
Laser	7.8	0.7	7.758	0.703
Etching	7.8	0.7	7.816	0.671
Milling	7.8	0.7	7.798	0.681

Table 4: Circuit board dimensions of bandpass filter 10 GHz, base material FR4

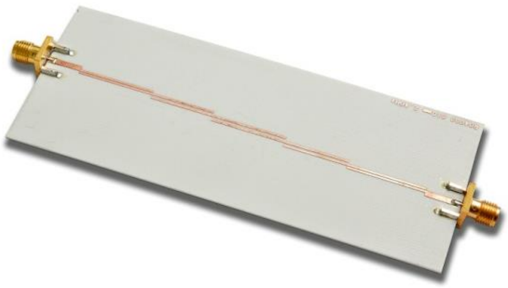

Figure 5: Bandpass filter 2.4 GHz made from Rogers RO4003C base material with connector plugs

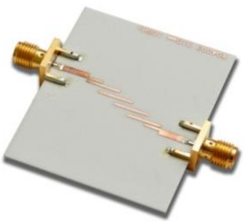

Figure 6: Bandpass filter 10 GHz made from Rogers RO4003C base material with connector plugs

Analysis

The measured values of the optical measurements of the circuit board geometry show that all processes are subject to deviations, see table 1 to 4. The deviations are the lowest in laser ablation. The classical etching process has the highest differences in width, while the length dimensions differ slightly. The average tolerances against the CAD data were 1.19% for laser ablation, 3.72% for milling and 4.75% for etching.

$$\varepsilon = \frac{1}{4}\sum_{s=1}^{4}\left(\left|\frac{x_{m_s} - x_{d_s}}{x_{m_s}}\right| + \left|\frac{y_{m_s} - y_{d_s}}{y_{m_s}}\right|\right)$$

Equation 1: Average tolerance (ε) of the microstrip dimensions as an average of the sums determined from the absolute values of each sample

Methodology for tolerance determination: The tolerance was determined from the quotient of the difference actual value to CAD setpoint divided by CAD setpoint. The deviations from x- and y-values were added and the average was determined for all four samples (see equation 1).

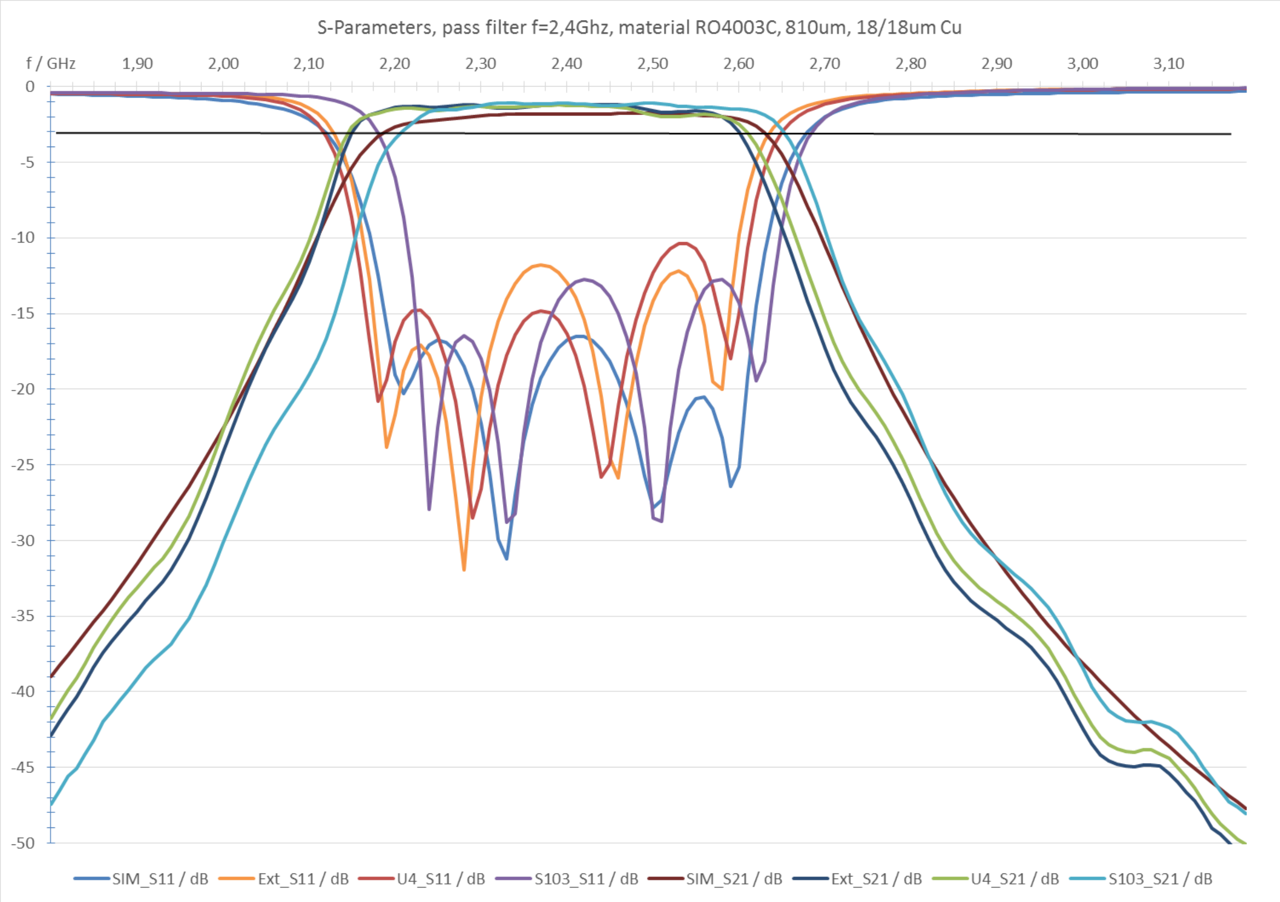

Diagram 1: S-parameter S11 and S21 at bandpass filter 2.4 GHz: CST simulation (**SIM**), externally etched circuit board (**EXT**), with LPKF ProtoLaser U4 (**U4**) and with LPKF ProtoMat S103 (**S103**) manufactured circuit boards

The transmission behavior of the bandpass filters is characterized by the measurement of the scatter parameters (S-parameters).
The S-parameter S21 describes the transmission of the filter from the input to the output, the parameter S11 the reflection at the input.
The S-parameters, differentiated into the three production methods, are shown in diagram 1 for the band pass filters 2.4 GHz, base material Rogers RO4003. The diagram shows that the parameters of the etched printed circuit board (EXT) and the circuit board produced by the ProtoLaser U4 (U4) are very close together. The parameters of the circuit board milled by the ProtoMat S103 (S103) move to higher frequencies.

For the FR4 material identical results were obtained for the 2.4 GHz bandpass filters produced in different methods.
The S-parameter curves for the 10 GHz bandpass filters on FR4 material show that the circuit board (U4) produced by the laser process exactly follows the simulated curve, while the chemically etched printed circuit board (EXT) moves significantly to lower frequencies. The mechanically milled circuit board (S103) shifts to higher frequencies.

The simulated and measured losses for all three technologies are about -5 dB at the center frequency, which is due to the material selection.
The frequency response of the 10 GHz filters made with Rogers RO4003C material is better compared to the FR4 substrate.

Conclusion of the comparison of the various manufacturing processes:
With the laser ablation method, the filters can be produced in the best possible way, while the externally etched and milled bandpass filters shows larger deviations between measured and simulated values.

	SIM	Ext	U4	S103
Fl [GHz]	2.2	2.16	2.16	2.22
Fh [GHz]	2.64	2.61	2.62	2.66
BW [GHz]	0.44	0.45	0.46	0.44
Fc [GHz]	2.41	2.37	2.38	2.43
Δf [GHz]	0.00	-0.04	-0.03	0.02
Dev [%]	0.00	1.66	1.24	0.83

Table 5: Measurements on the 2.4 GHz bandpass filter made from Rogers RO4003C material

	SIM	Ext	U4	S103
Fl [GHz]	9.71	9.57	9.68	9.78
Fh [GHz]	10.35	10.25	10.40	10.46
BW [GHz]	0.64	0.68	0.72	0.68
Fc [GHz]	10.02	9.90	10.03	10.11
Δf [GHz]	0.00	-0.12	0.01	0.09
Dev [%]	0.00	1.20	0.10	0.90

Table 6: Measurements on the 10 GHz bandpass filter made from Rogers RO4003C material

The results of the S-parameter measurements for the 2.4 GHz and 10 GHz bandpass filters made from Rogers RO4003C material are summarized in tables 5 and 6. Fl and Fh denote the lower or upper 3dB limit frequency of the filter, BW stands for the bandwidth ($BW = Fh - Fl$), Fc is the center frequency ($Fc = \sqrt{Fl\ x\ Fh}$) and Δf or rather Dev are the deviation of the center frequency referred to the simulated value.

The values in table 5 show that the differences in the filter properties analyzed between etched and laser-treated circuit boards are low at 2.4 GHz. The milled circuit board has a displacement of the center frequency of 20 MHz compared to the simulated value. A more significant difference is found in the 10 GHz band pass filter, see table 6.
The filter manufactured with the ProtoLaser has a center frequency of 10.03 GHz and thus a deviation from the simulation of only 0.1%. The other filters (milled / etched) have significantly larger deviations (0.9% / 1.2%).

Conclusion

The circuit boards produced with the ProtoLaser U4 have an identical or even better performance than the etched printed circuit boards.

Circuit boards milled with the ProtoMat S103 showed a shift to higher frequencies in the frequency response.

The production of the circuit board for the 10 GHz bandpass filter (outer dimensions 4 x 5 cm) took only 4 minutes with the LPKF ProtoLaser U4. The ProtoMat S103 needed twice the time. The externally etched printed circuit boards had a delivery time of one week. On the base of the frequency measurements, the RF designer has the option of modifying his circuit board layout and quickly manufacture it in-house with the ProtoLaser U4 in order to further develop or rather optimize the board design. .

For RF designers, the LPKF ProtoLaser U4 is the ultimate tool for fast prototyping as well as for the production of smaller series of the developed RF circuit boards.

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