Microwave Analogue FIR-Filter

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***Abstract* — Analogue FIR-filters have been proposed for the realization of wideband array antennas, where they replace conventional amplitude/phase control and true-time-delay sections. The filter concept presented in this contribution employs one input and one output transmission line supporting traveling waves. The design has to be different to the traveling wave amplifier design because the signals fed through the bi-phase amplitude controls (attenuator, coefficients a_i) to the output line are not in-phase! We thus need high impedance at input and output ports of the attenuator circuits.**

A proof-of-concept circuit was designed and tested which employs three transistors and which operates at a "scaled-down" frequency band (VHF). A full FIR-filter structure with N = 4 sections was built and tested and will be compared to theoretical predictions.

I. Introduction

Finite Impulse Response (FIR) filter structures, Fig. 1, are widely used in digital signal processing for the realization of filter responses with prescribed frequency behaviour, e.g. as equalizers, correlators and matched filters in communications and recently also as element signal weight controls in smart antenna arrays, see overview [1]. In our companion paper [2], we present the concept of electronic steered microwave array antennas using analogue FIR-filters at each element with the aim of realizing wideband, frequency independent pattern characteristics.

The aim of this paper is to present the concept for broadband analogue FIR filter circuits for the microwave frequency range and discuss proof-of-concept circuit design and results.

II. Concept of Microwave FIR-Filter

The principle design of FIR-filter due to Fig. 1 combines time delay sections with amplitude control (attenuator) circuits. While the amplitude control circuits

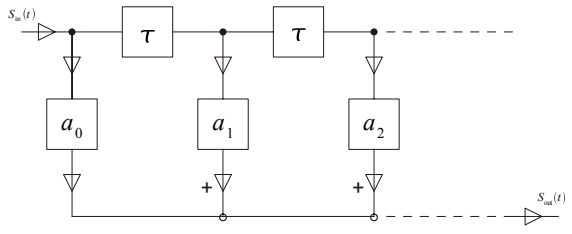

Fig. 1. Finite Impulse Response filter principle design

realize the real amplitude coefficients a_i , Microwave realizations have to take into consideration the inherent delays, parasitic elements and wideband impedance transformation properties of circuits and their connections. Therefore, our circuit is based on the traveling wave concept, similar (but not identical) to the design of distributed amplifiers, e.g. [3].

Our circuit concept is shown in Fig. 2: The input signal $s_{in}(t)$ is fed to an input transmission line and a traveling wave is created propagating towards the

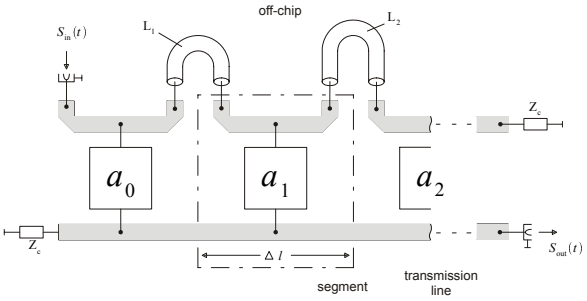

Fig. 2. Circuit concept for a microwave analogue FIR filter

matched end termination. The transmission line is segmented with interconnecting extra transmission lines representing the time delay units (in the circuit diagram with lengths L_i) which may be realized off-chip in order to keep the circuit size low; they may also be realized on-chip as lumped LC networks, a similar approach as used in a microwave equalizer circuit recently published [4]. Within each segment of the transmission line, there is one bi-phase variable attenuator connected to the input signal transmission line with the weight factor ideally between -1 and +1 ($-1 < a_i < 1$). The input impedance of the attenuator has to be high in order not to disturb the forward traveling wave on the input-line, thus we assume this port to be realized by the gate / source terminals of a FET. The attenuated signal is coupled to the output transmission line on the other side, where we also terminate by a matched load at one end while the other port supplies the output signal $s_{out}(t)$ to a matched load. Signal injection from each segment has to sum up on the output transmission line which can be achieved by the creation of a traveling wave on the output transmission line and assuming superposition of contributions from each segment. Note the difference with respect to a traveling wave amplifier: The output signal contributions are <u>not</u> in-phase in our case! Note also that each current source will set-up a wave in either direction, while only those waves traveling towards the output port are used for $s_{out}(t)$.

We thus require high source impedance for the attenuator output terminals making the attenuator act as a

current source (rather than an impedance-matched generator) and thereby avoiding heavy resistive loading of the output transmission line. We may describe our attenuator circuit also as voltage controlled current source, or bi-phase transconductance amplifier, and we therefore find the drain / source terminals pair of a saturated GaAs FET to be a viable solution for this purpose. In principle, we could imagine a single FET connected with its gate to the input line and with its drain to the output line, Fig. 3.

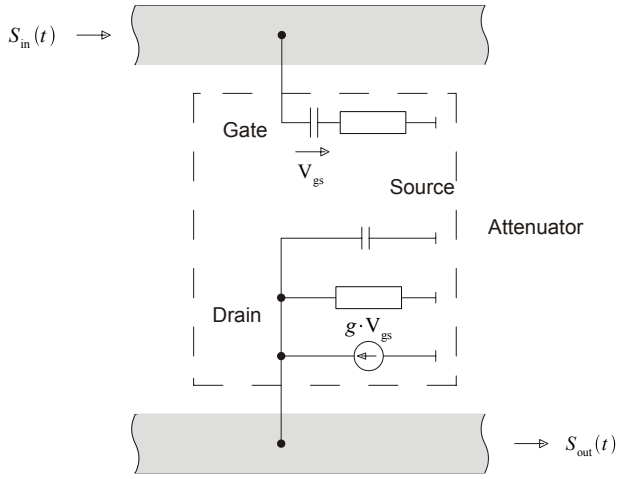

Fig. 3: RF equivalent circuit of a high input impedance / high output impedance attenuator circuit

However, the full circuit developed in our project uses three transistors in order to realize the bi-phase characteristics instead of just one transistor. The first transistor functions as an unbalanced-to-balanced circuit with in-phase and anti-phase outputs driving the two second stages. By application of appropriate bias to the second stage transistors, either a signal from the in-phase second stage or from the anti-phase second stage feed into the output transmission line.

All segments in our circuit are constrained to be realized by the same pitch Δl in the input- and output transmission lines. In that case we can condense the net-effect of the N segments of the FIR-circuit to one single transmission line of length $N\Delta l$ and consider the remaining circuit as ideal, concentrated FIR-circuit (including the required delay lines) plus a fixed average time delay τ_g due to the bi-phase attenuator group delay (which is around 2 ns), see Fig. 4.

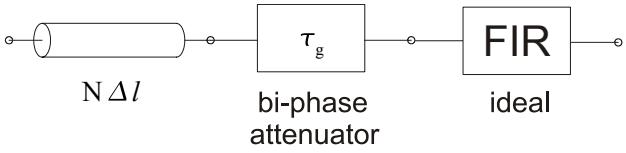

Fig. 4. Block diagram representation of microwave FIR-filter circuit

The total extra delay from the transmission lines and the group delay applies to all possible signal paths through the filter and all possible filter settings and to all individual filters in the same way, e.g. in an antenna array, so that we may neglect it or subtract it completely in most applications. The frequency domain response of the FIR structure therefore can be written as

$$H(f) = e^{-j2\pi f(N\Delta l / v_{ph} + \tau_g)} \cdot \sum_{i=0}^{N-1} a_i \, e^{-j2\pi f \cdot i\tau}$$

where the first factor is due to the constant delay and the second factor characterizes an ideal FIR-filter.

The size of the required delay per stage is discussed in our companion paper [2] for the antenna array application: In an example array design, we would need 20 antenna elements, each connected to one FIR-filter and each filter consisting of about 10 stages. The delay per stage was chosen to be equivalent to the propagation delay in free space from one element to the next d/c_0. For an antenna array operating up to 10 GHz, this would require d = 15 mm and τ = 50 ps.

III. Proof-of-Concept

The critical component of the FIR-filter circuit is readily identified as the bi-phase attenuator. It is required to have high input and output impedances and flat amplitude and group delay transfer characteristic over a broad band and over the dynamic range. Such circuits presently are not available commercially (only 50 Ω-impedance matched attenuators and modulators are available) so that we had to develop a suitable attenuator circuit before implementing the FIR filter circuit. Since, in an ultimate microwave circuit realization for e.g. 3 to 10 GHz (as for UWB-pulse applications) expensive monolithic integration would be applicable, a proof-of-concept circuit was designed for a scaled-down "model" frequency range of a few 100 MHz compatible with conventional PCB technology and the use of surface mount devices. Our bi-phase attenuator lab-model as shown in Fig. 5 uses a first stage (input) configured as an unbalanced-to-balanced source follower stage while the second stage (output) of the circuit employs two transistors in common source configuration; we use CF739 dual-gate FETs which have the advantage of particularly high output impedance, high trans-conductance and the availability of a second gate for gain control. The two output stage transistors' drain R.F. currents are combined (shunt connection) at the output transmission line, but under operating conditions, only one transistor is conducting at a time, making the weight factor a_i either positive or negative.

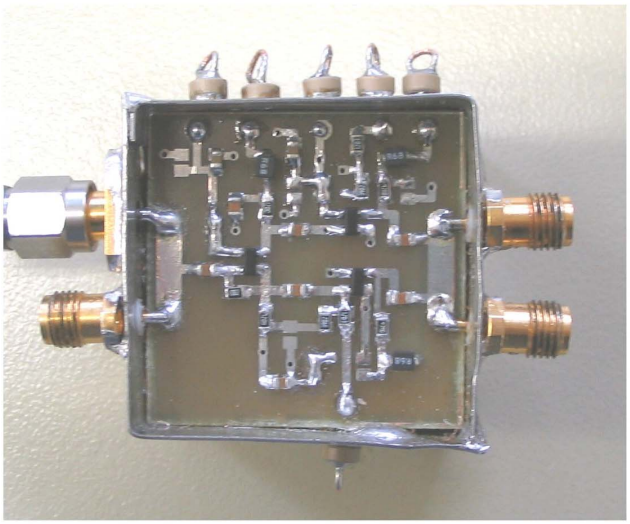

Fig. 5(a) Photograph of experimental bi-phase attenuator circuit

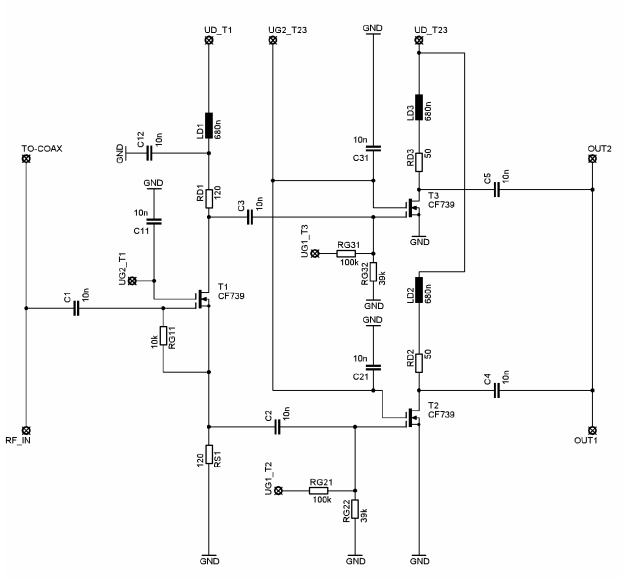

Fig. 5 (b) Schematic of the realized bi-phase attenuator using three transistors

First measurements of the scattering parameters of the lab-model have shown wide dynamic range, flat amplitude response and only little group delay dispersion over frequency as shown in Fig. 6. The measurement of the transmission scattering parameter $|s_{21}|$ was done loading the second input-port and the second output port by an extra 50 Ω-termination in order to mimic the traveling wave environment of the ultimate filter circuit. We can realize that the attenuator circuit can be steered to a few dB of amplification ($a > 1$) and exhibits a dynamic range of more than 30 dB.

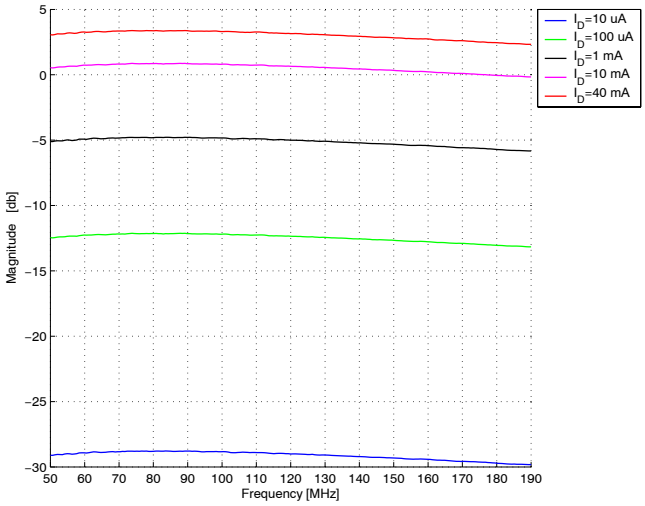

Fig. 6 Insertion loss of bi-phase attenuator as a function of second stage drain current

A full FIR filter circuit lab-model using four sections based on the present attenuator design and coaxial delay lines was built and tested. Results of this experiment and comparison with theoretical predictions will be reported at the conference.

IV. Conclusion

The concept of an analogue microwave FIR-filter was discussed and a proof-of-concept experiment at VHF presented. Future work will be directed towards improving insertion loss- and group delay- flatness and toward the realization of filter-circuits at microwave frequencies, including the consideration of monolithic fabrication.

References

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