
Proceedings Paper:

Hunter, IC, Musonda, E, Parry, R et al. (2 more authors) (2013) Transversal directional filters for channel combining. In: Microwave Symposium Digest (IMS), 2013 IEEE MTT-S International. IMS 2013: IEEE International Microwave Symposium, 02-07 Jun 2013, Seattle, WA, USA. Institute of Electrical and Electronics Engineers , pp. 1-4. ISBN 978-1-4673-6177-4

https://doi.org/10.1109/MWSYM.2013.6697427

Transversal Directional Filters for Channel Combining

Ian Hunter[1], Evaristo Musonda[1], Richard Parry[2], Michael Guess[2], Meng Meng[1]

[1] Institute of Microwaves and Photonics, School of Electronic and Electrical Engineering, University of Leeds, Leeds LS2 9JT, UK.

[2] Radio Design Ltd, Shipley Wharf, Wharf Street, Shipley ,West Yorkshire,BD17 7DW, UK

Abstract — A new concept for the design of power combiners based on matched directional filters is presented. The directional filters consist of individual balanced sections composed of hybrids and single resonators. Each of the sections corresponds to a pole of an all-pass function composed of the sum of S_{11} and S_{12} of the desired filter transfer function. A simple synthesis method is presented. The filter combiner has the advantage of ease of tunability because each pole is associated with a single resonator. Furthermore, no cross couplings are required to realize finite frequency transmission zeros.

Index Terms — directional filters, combiner, power divider, general Chebyshev filter.

I. INTRODUCTION

Recent requirements to share sites for mobile communication base stations require the use of diplexers or multiplexes so that two or more bands may be transmitted on a single antenna simultaneously allowing service providers in the same vicinity to share antennae. This paper demonstrates a novel approach for designing combiners based on Directional Filters (DF) which could be used in Long Term Evolution (LTE) base stations.

A DF is a matched four-port device shown in Fig.1 with an input at port 1. Port 4 is isolated and the transmission functions at port 3 and 4 correspond to S_{11} and S_{12} of a two-port filter. The concept of directional filtering has been presented in the literature over the past decades. Common designs use striplines and waveguide technologies [1] [2] and others are presented in [3] [4]. The principles of operation of a DF used in this paper are an extension on the work presented in [5].

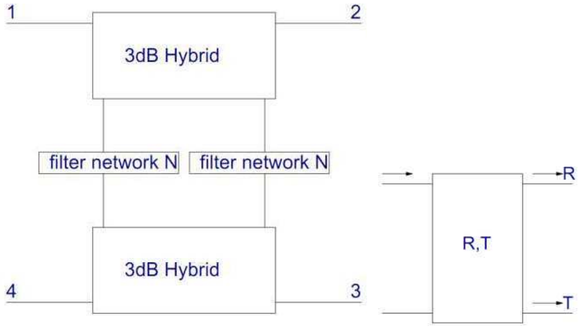

Fig. 1. A single section of a DF and a simplified diagram.

A synthesis method for DF is presented with various approximations to derive a simplified and realizable equivalent circuit. The design is based on a pole placement method where each single section of a DF is singly tuned to provide a pole of a bandpass filter. This may be realized by inserting two networks between a pair of 3dB hybrids. Cascading these sections allows multi-pole response equivalent to the characteristics an N^{th} degree filter. As in a transversal array, each section of the network corresponds to a pole of the filter's admittance parameters [6]; each cascaded section in a DF realizes a pole of its S parameters. As opposed to conventional techniques of designing combiners, this technique does not involve the design of channel filters or junctions. Instead, a single bandpass filter characteristic is used such that the insertion and return loss of this bandpass filter provides the forward transmission characteristics of each band. The design is made from a lowpass filter prototype and bandpass characteristics are achieved by standard transformations.

The concepts were validated with a design of a cellular combiner with practical specifications used in uplink 800 MHz LTE bands. The design is based on the characteristics of a 4th order general Chebyshev filter and the required selectivity is achieved by two transmission zeros close to the passband. The cellular combiner was fabricated using coaxial resonators. The proposed solution achieves good isolation between the input ports, return loss and minimum in-band insertion loss

II. DESIGN THEORY

A. Cascaded directional filters

As shown in Fig.1, when identical filter networks (network N) are inserted between a pair of 3 dB hybrids, power incident at port 1 emerges at port 2 with the return loss of network N and at port 3 with the insertion loss. This single section of a DF works as the basic building block for the combiner. Regarding the simplified diagram in Fig.1, the response of this section is given in (1).

$$\begin{aligned} R &= jS_{11} \\ T &= jS_{21} \end{aligned} \qquad (1)$$

The single section of DF in Fig.1 can be cascaded as shown in Fig.2 with its response given in (2). By cascading, higher order responses can be achieved.

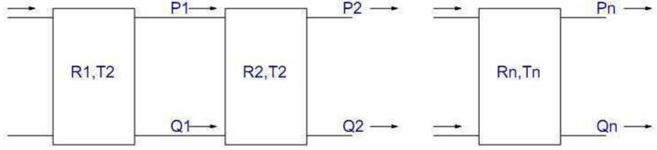

Fig. 2. Cascaded sections of DFs

$$\begin{aligned} P_n &= P_{n-1}R_n + Q_{n-1}T_n \\ Q_n &= P_{n-1}T_n + Q_{n-1}R_n \end{aligned}. \tag{2}$$

From (2), we could derive (3) which is the basic equation we will use for the synthesis of Nth degree combiners.

$$P_n + Q_n = \prod_{i=1}^{n}\left(R_i + T_i\right) \cdot \tag{3}$$

B. Decomposition of filter characteristics

The S parameters of a lossless filter network may be expressed as rational polynomials as in (4) and the sum of these parameters is given in (5) in which n is the filter order, z_i represents a zero and p_i represents a pole.

$$S_{11} = \frac{F_{11}}{E} \cdot \qquad S_{21} = \frac{P}{E} \tag{4}$$

$$S_{11} + S_{21} = \frac{F_{11} + P}{E} = \frac{\prod_{i=1}^{n}(s - z_i)}{\prod_{i=1}^{n}(s - p_i)} . \tag{5}$$

According to (6), each pole of a filter characteristic could be realized by a single DF section and a higher order response could be formed by cascading DF. From the alternating pole method [7], it is shown that a zero in (5) is either the same as a corresponding pole or as the complex conjugate of a pole.

$$\frac{s - z_i}{s - p_i} = R_i + T_i \cdot \tag{6}$$

C. The design of directional filers

The next goal is to find appropriate networks N which may be used to provide R_n and T_n. A simple resonator network as shown in Fig.3 is used for this purpose with its S parameters given in (7). The network consists of a capacitance C and a frequency invariant reactance B which should be included to realize complex poles.

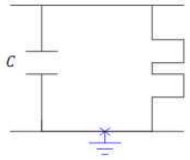

Fig. 3. Filter network N to provide the required pole in the DF.

$$\begin{aligned} S_{11} &= -\frac{s + jB/C}{s + jB/C + 2/C} . \\ S_{21} &= -\frac{2/C}{s + jB/C + 2/C} \end{aligned} \tag{7}$$

Comparing (7) with (6), we obtain the values for the capacitance and frequency invariant reactance according to the values of poles as in (8). It should be noted that in the case when z_i is of the complex conjugate of p_i, a 180° phase shifter should be introduced after the ith section.

$$\begin{aligned} C_i &= -\frac{2}{\mathrm{Re}(p_i)} . \\ B_i &= \frac{2\,\mathrm{Im}(p_i)}{\mathrm{Re}(p_i)} \end{aligned} \tag{8}$$

In order to derive a realizable cascaded DF network, the branches for the 90° hybrid are replaced by an equivalent π network of inductances. Elements of the inductances of the π network are then merged with the resonators after the lowpass to bandpass transformation. The final circuit for the single section DF is given in Fig.4. The element *L'* and *C'* can be realized by conventional resonators such as coaxial and dielectric resonators. The inductances L_v represent the input couplings to the resonators and L_m represent inter couplings between the resonators.

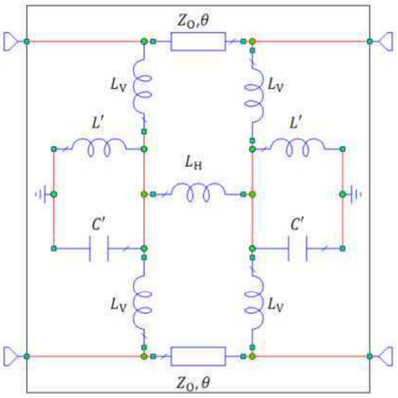

Fig. 4. Equivalent circuit of a single section of a DF.

An EM model for Fig. 4 based on coaxial resonators is shown in Fig.4. The main branch of the hybrid is realized by a 50Ω line. The input couplings are realized by non-resonating nodes and the inter resonator coupling is realized by a window.

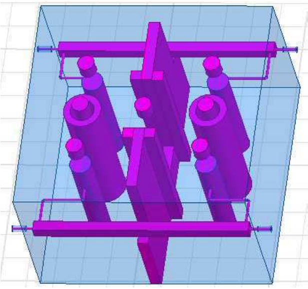

Fig. 5. EM simulation of single DF section in HFSS.

III. THE DESIGN OF A COMBINER

With cascaded DF, high performance combiners may be designed. Because the two passbands are formed by the insertion and return loss of a single filter characteristic, the two channels of the combiner designed have no interaction even when the two bands are very close to each other. A combiner with two passbands of 832-841.5 MHz and 842.5-852MHz is used as an example to illustrate the design theory. The required passband return loss is >18dB and the insertion loss is <1dB.

A 4th order general Chebyshev filter is used. Because the two bands are close to each other, the filter characteristic should have a steep transition and is realized by two transmission zeros close to the passband. The transmission zeros are at 1.15j and 1.45j in the lowpass domain. After synthesizing the general Chebyshev response using method given in [7], the capacitance and frequency invariant reactance of each resonator are calculated according to (8).

A lowpass to bandpass transformation is applied to each resonator and the network is combined with the equivalent circuit of the 90° hybrid. After some scaling, the circuit for each section is the same as the one shown in Fig.4. Then four DF sections are cascaded. The circuit model is then simulated in ADS and the result is shown in Fig.6 with solid lines.

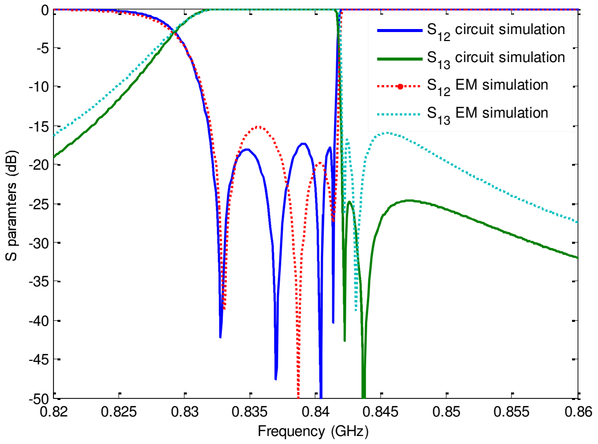

Fig. 6. Simulation result for the combiner (Solid line for the circuit simulation and dashed line for the combined EM/circuit simulation).

An EM model for each DF section was built and tuned in HFSS. Each section has a different resonant frequency and couplings. For this lossless design, we used PEC for conductors. The S parameters of each section were then put in ADS and connected by transmission lines. The result of this combined EM and circuit simulation is given in Fig.6 as the dashed line response. The EM model of the whole structure is shown in Fig.7. The hardware is presently being fabricated. Because each DF section controls one pole of filter characteristic, they may be tuned independently. In addition, no cross couplings are required when realizing transmission zeros and thus through tuning, different kinds of responses may be achieved by the same structure.

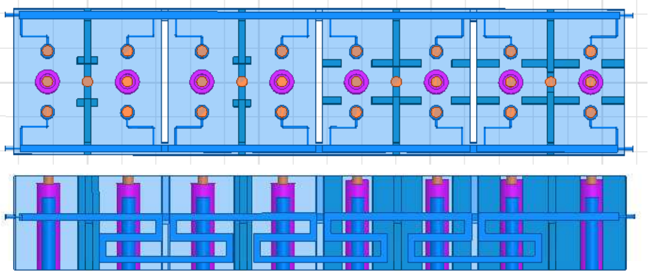

Fig. 7. EM model for the combiner (top view and side view).

IV. CONCLUSION

A new concept for designing channel combiners based on directional filters has been presented along with a synthesis method. Utilizing the insertion loss and return loss of a single filter characteristic, the designed combiner has no interaction between the two bands. The combiner is simple to tune as each section is independent of the others and the structure requires no cross couplings. Furthermore, because each of the DF sections corresponds to a pole of the S parameters of the filter, device with non-uniform Q resonators may be designed. This will be discussed later.

REFERENCES

[1] Matthaei G. L., Young L., and Jones E. M. T., Microwave Filters, Impedance Matching Networks and Coupling Structures, Norwood, MA: Artech House, 1964, pp. 165–173, 243–252.

[2] Wanselow, R.D. and Tuttle, L.P. Jr., “Practical design of strip transmission line half-wavelength resonator directional filters”, Trans. IRE, Jan. 1959, vol. MTT-7, pp. 168-173

[3] Wing, O., “Cascade Directional Filter”, Microwave Theory and Techniques, IRE Transactions, 1959, vol. 7, vo. 2, pp. 197-201

[4] Coale, F.S., “A Travelling-Wave Directional Filter”, Trans. IRE, Oct. 1956, vol. MTT-4, pp. 256-260

[5] Rhodes, J. D. and Mobbs C.I., “Explicit Design of remote-tuned combiner for GSM and WCDMA signals”, International Journal of Circuit Theory and Applications, September – December 2007, vol. 35, no.5-6, pp. 547-564

[6] Meng Meng; Hunter, Ian C.; , "The design of parallel connected filter networks with non-uniform Q resonators," Microwave Symposium Digest (MTT), 2012 IEEE MTT-S International, vol., no., pp.1-3, 17-22 June 2012’

[7] R. J. Cameron, "Advanced Coupling Matrix Synthesis Techniques for Microwave Filters," IEEE Trans. Microw. Theory Tech., vol.51 , no.1 , pp.1-10, Jan. 2003.