Introduction

Filters and combiners are essential components of many broadcasting antenna systems. They are used for selecting frequencies, suppressing disturbing emissions and noise sidebands, avoiding interference products, combining several channels into one common antenna with low loss and for separating channels. In certain cases, separate antenna diagrams for individual channels can also be generated.

Selection of parameters

According to their use as elements of a system, filters are constructed as two-port networks and are matched to the impedance of the other system elements (e.g. transmitter, receiver, antenna or connecting cables) at both the input and the output.

$P_2 = P_1 - P_r - P_v$

P_1 = Input power

P_r = Reflected power

P_v = Power loss through filter

P_2 = Power transmitted

Fig. 1: Filter with connections

Frequency response

The attenuation usually depends on the frequency used. This relationship is shown graphically by the following diagram of a typical attenuation curve for a filter.

A plot of the attenuation VS frequency shows the typical filter curve. The attenuation is the logarithmic ratio between input power and transmitted power.

$$a\,/\,\mathrm{dB} = 10 \log \frac{P_1}{P_2}$$

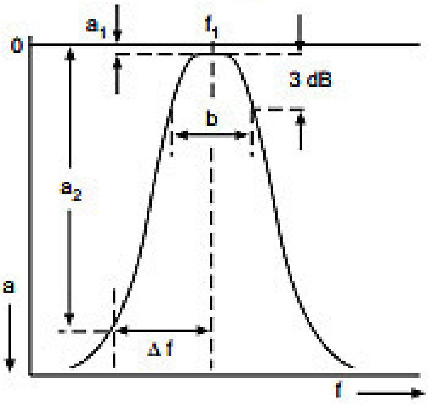

Fig. 2: Frequency response of a filter tuned to frequency f_1 with insertion loss a_1, stop band attenuation a_2 at the frequency of $f_1 - \Delta f$ and with bandwidth b at 3 dB.

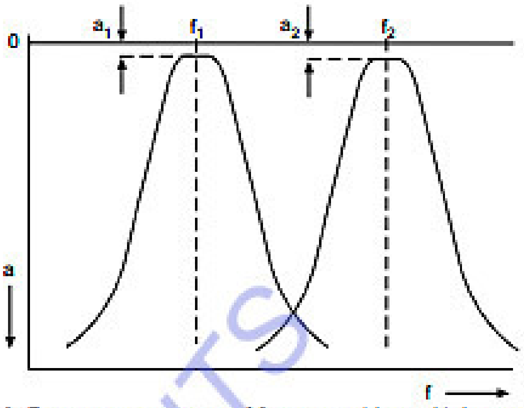

Fig. 3: Frequency response of 2-way combiner with insertion losses of a_1 and a_2 at the frequencies f_1 and f_2.

Matching

As a measurement of how a filter is matched the return loss a_r, which is the logarithmic relationship between the input and reflected power, is displayed.

$$a_r\,/\,\mathrm{dB} = 10 \log \frac{P_1}{P_r}$$

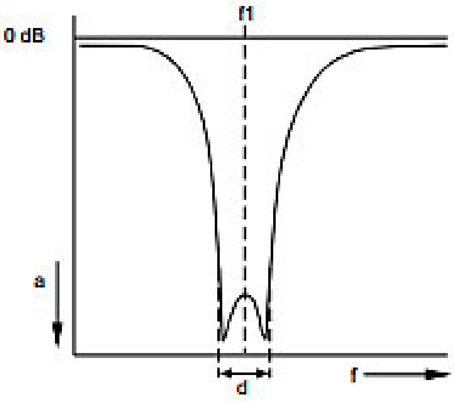

Fig. 4: Return loss of a 2-pole bandpass filter tuned to the frequency f_1 and with pass band bandwidth d.

The return loss a_r, reflection coefficient r and VSWR factors are all related according to the following formulas:

$$a_r = -20 \log |r|$$

$$s = \frac{1 + |r|}{1 - |r|}$$

Filters

Where used in broadcasting systems, filters are normally set up as a combination of several λ/4 resonators. The Q factor of the resonators is very important with regard to the electrical data and is influenced by the shape and volume of the filter as well as by the conductivity of the material used.

The selectivity of the filters used for combiners has a decisive influence on the minimum spacing required between the transmitters to be connected into one common antenna. If the frequency spacing is narrow then the filters must similarly be tuned in a very narrow way. But this will cause an increase in the insertion loss (see fig. 5) resulting in the filters becoming hot. This problem can be avoided if filters of greater volume are used which have a relatively lower insertion loss.

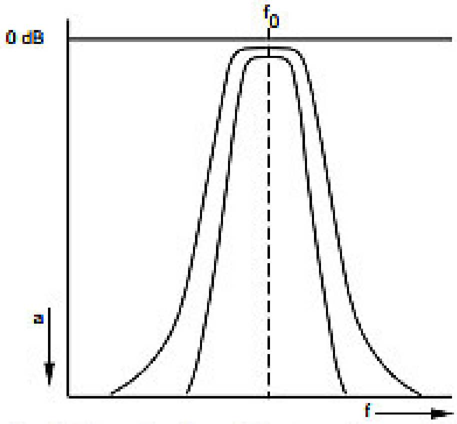

Fig. 5: Examples of two different tuning possibilities for a bandpass filter. Narrower tuning will result in higher insertion loss.

Directional couplers

A directional coupler is a reciprocal four-port construction, whereby two of the ports are isolated from each other. For example, the power entering port 1 (see fig. 6) is split up to ports 2 and 3, whereas port 4 is isolated. The power fed into the other ports is similarly split.

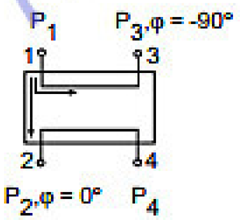

Fig. 6: Directional coupler with two coupled lines.

If every port is terminated with a reflection-free load, then the following formulas apply:

Coupling attenuation

$$a_k = 10 \log \frac{P_1}{P_2}$$

Directivity

$$a_d = 10 \log \frac{P_2}{P_4}$$

If the coupling range of a transmission-line coupler is λ/4 at the center frequency f_m then the coupling attenuation over a frequency range of $f_1/f_2 = 2$ is almost independent of the frequency. For example, with a 3-dB directional coupler there is a divergence of ± 0.4 dB and phase difference of 90° occurs between the signals at ports 2 and 3, which is also almost independent of the frequency.

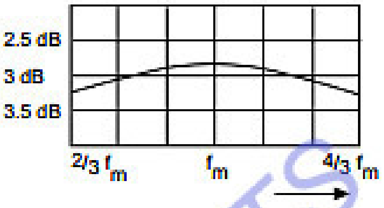

Fig. 7: Coupling attenuation for 3-dB transmission-line coupler of $\lambda_m/4$ length.

Combiners

Combiners are a combination of frequency-selecting components (e.g. filters, stretchlines) with nodes and connecting elements (e.g. directional couplers, starpoints). In high quality combiners bandpass filters are used in preference to stop band filters.

Starpoint combiners

Starpoint combiners for n channels consist of n bandpass filters with outputs that are connected to a common starpoint.

The individual bandpasses are tuned to the respective frequencies. Since the bandpass filters are mismatched outside their pass bands (with inductive coupling the impedance almost approaches a short-circuit) the impedance can be transformed up to very high levels by selecting the appropriate length for the connecting cables between the filters and the starpoint. This means that for every input the transformed impedances of all the other inputs are very high at the starpoint which produces a very low parallel load at the antenna output.

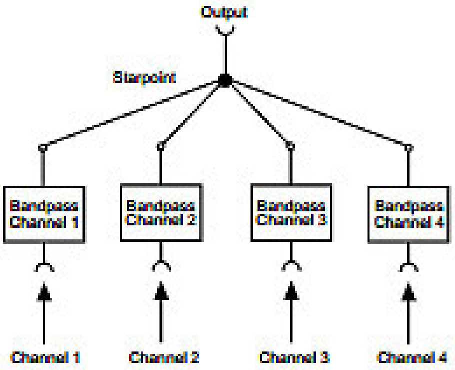

Fig. 8: Starpoint combiner for 4 channels

Directional filter combiner

Directional filter combiners are a combination of filters and 3-dB couplers. One module consists of two band-pass filters, two 3-dB couplers and a load (see fig. 9). One input is narrowband (NB), corresponding to the band-pass curve of the band-pass filter. The other input is broadband (BB), corresponding to the operating range of the 3-dB coupler.

Compared to other types of combiners that can be produced at less expense, directional filters offer a number of useful advantages:

- Simple set-up of multiple combiners through cascading several modules
- Very high isolation between the narrowband inputs of a cascade
- Broadband matching at all inputs
- Easy extension of existing combiners by adding new modules.

Function of module

The signal fed into the narrowband input (NB) is split into two halves by the 3-dB coupler (1), both of which pass through one of the band-pass filters to the 3-dB coupler (2) and are then added in equal phase at its output due to the 3-dB coupler's function. At the broadband input (BB) the two partial signals are anti-phase and therefore practically no signal appears at this port. The broadband input is isolated from the narrowband input by the directional coupler, but this also depends on the band-pass filters being identically tuned.

The frequency of a signal fed into the broadband input (BB) lies within the stop band of the band-pass filters. The signal is split into two halves by the 3-dB coupler (2) and reflected completely by the band-pass filters and proceeds to the output after co-phase addition. The narrowband input is isolated from the broadband input by the directional coupler, as described above, but there is additional isolation due to the stop band attenuation of the band-pass filters.

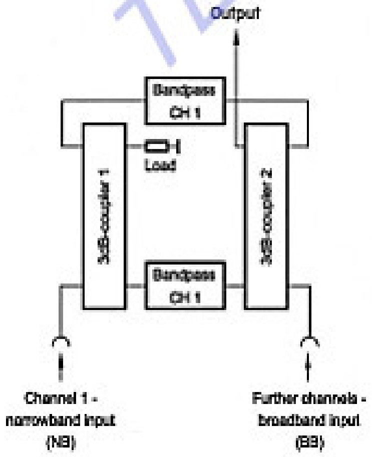

Fig. 9: Diagram of a directional filter

Cascading of modules

Multiple combiners are easily set up by using several modules with the output of each module feeding the broadband input of the next module. The number of channels possible in a given frequency band is limited only by the minimum spacing between the signals. But practical limitation can also arise because the insertion loss for each additional module increases by 0.05 – 0.1dB and can assume intolerable values. The power rating of the 3-dB coupler at the output also can limit the number of channels in practice.

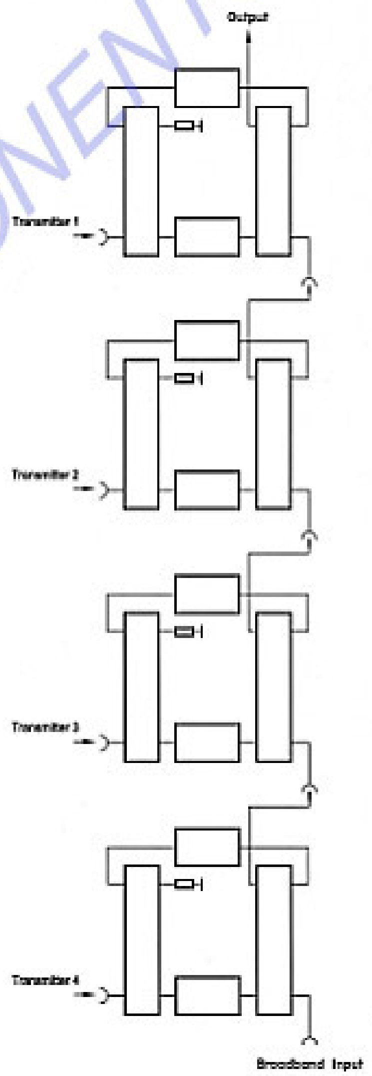

Fig. 10: Diagram of a directional filter combiner with four modules