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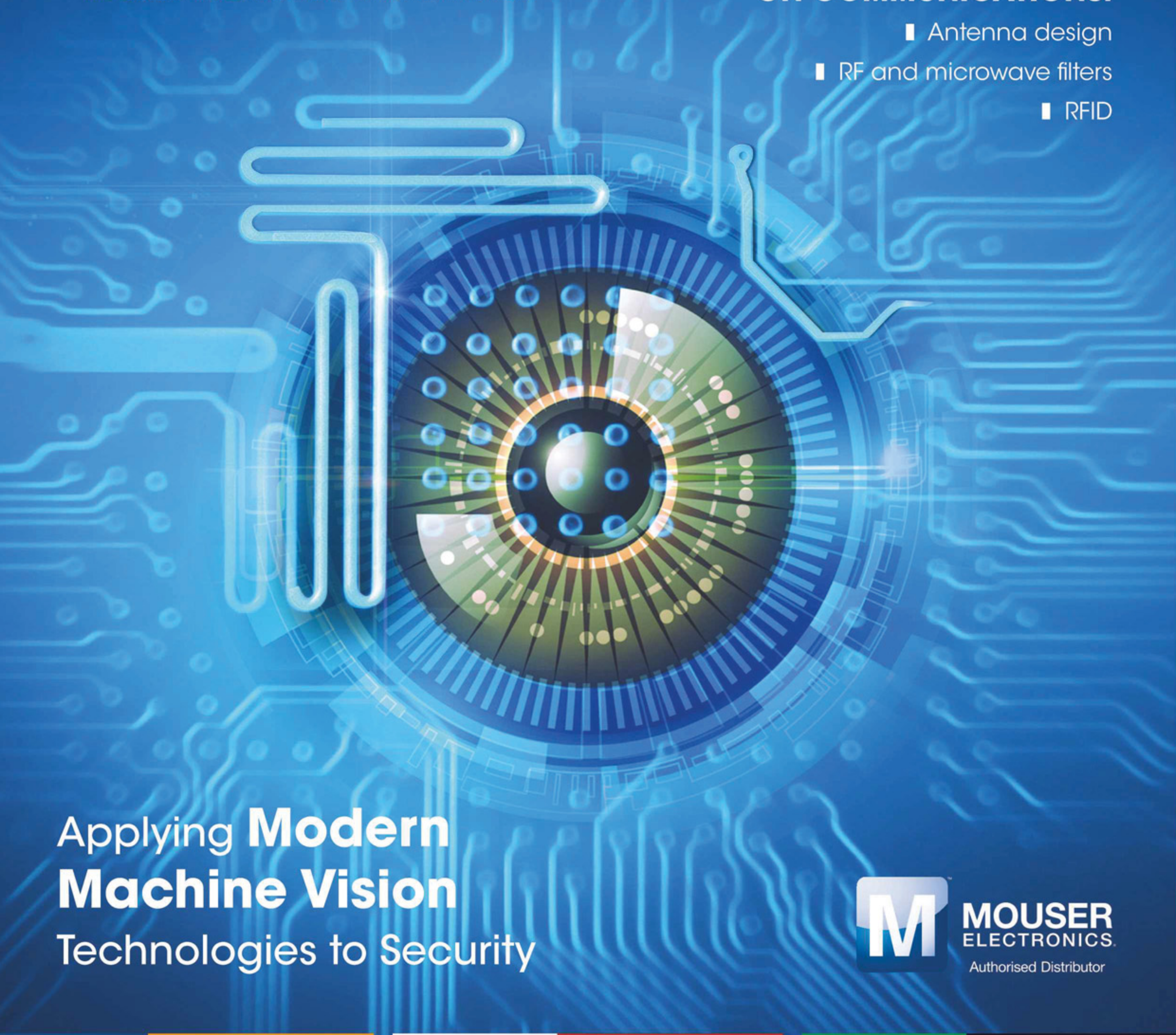

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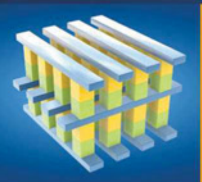

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CHARACTERISTICS OF MICROWAVE AND RF SIGNAL FILTERS

BY **STOJCE DIMOV ILCEV** FROM DURBAN UNIVERSITY OF TECHNOLOGY IN SOUTH AFRICA

Microwave (MW) and RF bandpass filters allow through frequencies within a certain range and reject or attenuate frequencies outside that range. Examples of analogue electronic bandpass filters are an RLC circuit (resistor/inductor/capacitor) or an RC circuit. Bandpass filters can also be created by combining lowpass filters with highpass filters.

'Bandpass' is different from 'passband' as it refers to an actual portion of affected spectrum, hence one might say "a dual bandpass filter has two passbands". An ideal bandpass filter has a completely flat passband (e.g. no gain or attenuation throughout), and would completely attenuate all frequencies outside the passband.

However, in practice no bandpass filter is ideal and it does not attenuate completely all the frequencies outside the desired frequency range. In particular, there is a region just outside the intended passband where frequencies are attenuated but not rejected. This is known as the filter roll-off, usually expressed in dB of attenuation per octave or decade of frequency.

Generally, the design of a filter seeks to make the roll-off as steep as possible, thus allowing the filter to perform as close as possible to its intended design. Often, this is achieved at the expense of passband or stopband ripple.

Filters Categorization

In general, all filters have the property of removing unwanted frequencies from a signal. They can be divided into two classes: passive (made of capacitors, resistors, inductors) and active (involving an amplifier). Filters can be further categorized into four types: lowpass (removes high frequencies), highpass (removes low frequencies or DC), bandpass (removes a range of frequencies on both sides of a band) and notch, reject or bandstop (removing frequencies in the middle), see Figure 1.

The bandwidth of a filter is simply the difference between the upper and lower cutoff frequencies. The shape factor is the ratio of bandwidths measured using two different attenuation values to determine the cutoff frequency; e.g. a shape factor of 2:1 at 30/3dB means the bandwidth measured between frequencies at 30dB attenuation is twice that measured between frequencies at 3dB attenuation.

Terminology parameters of a MW/RF filter design are signal-to-noise (S/N) ratio; the bandwidth is a range of frequencies as G(jw) > 0.707; the cutoff frequency is of passband frequency; and the break point of a filter is the point of -3dB.

The signal-to-noise (or signal-to-interference) ratio, S/N (or SNR) is defined as:

$$S/N = 20\log_{10} (E_{th}/V_{SM}) = 10\log_{10} (W_S/W_N);\ \text{in dB}$$

where W_S and W_N are the signal and noise power respectively, while E_{th} and V_{SM} are the root mean square (rms) values of the voltages. Thus, G(jw) is a complex number for any angular frequency, w, so its plot consists of complex numbers.

Bandpass Filters

One simple use for passive filters is in audio amplifiers, loudspeaker crossover filters and pre-amplifier tone controls among others, see Figure 3A.

Active bandpass filters are slightly different in that they are

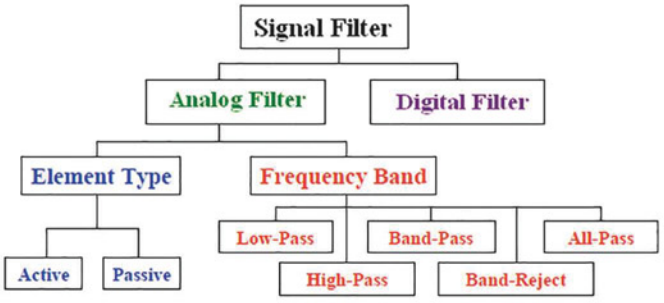

Figure 1: Classification of MW and RF filters

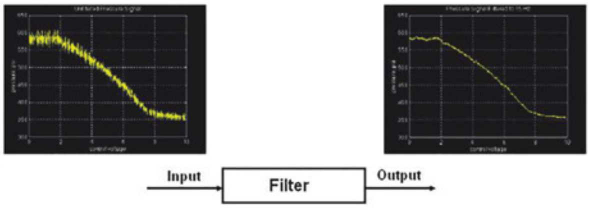

Figure 2: Outline of a filter design

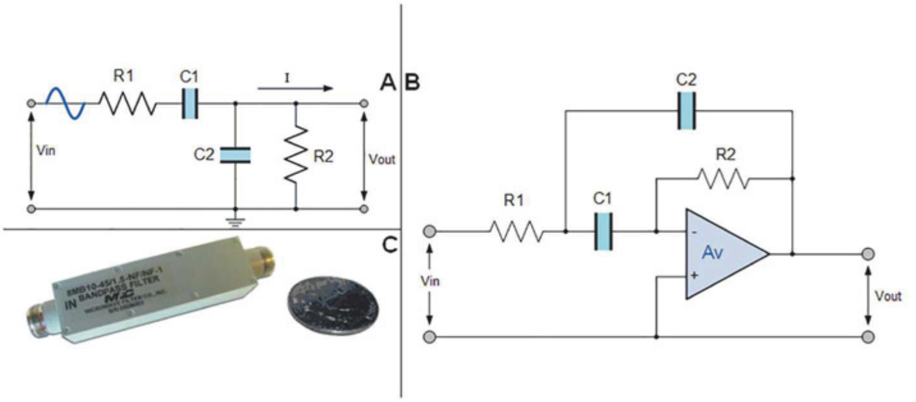

Figure 3: Passive and active bandpass filter circuit and amplitude

frequency-selective filter circuits used in electronic systems to separate a signal at a particular frequency or a range of signals that lie within a certain band of frequencies; see Figure 3B. An active filter uses active components, such as amplifiers, to improve the performance and predictability of a filter, whilst avoiding the use of inductors, which are typically expensive compared to other components.

Figure 3C shows a miniature bandpass filter, model 8 MB10 100/10- PN/PN-1 of the Microwave Filter Company's MB series; they use high-quality components for narrow- and wide-band filter applications in the range 0.5-500MHz.

> “In general, all filters have the property of removing unwanted frequencies from a signal, which can be divided into two classes: passive (made of capacitors, resistors, inductors) and active (involving an amplifier)

The bandpass filter is by far the most common filter used in MW and RF applications. The frequency range passed by a bandpass filter is determined by the specification for calculating the “resonant” or “centre frequency” (f_r) point where the output gain is at its maximum or peak value:

$$f_r = \sqrt{f_L \times f_H}$$

Here, f_L is the lower -3dB cutoff frequency point, and f_H is the upper -3db cutoff frequency point. This peak value is not the arithmetic average of the upper and lower -3dB cutoff points as one might expect, but the “geometric” or mean value.

Bandstop Or Bandreject Filters

Bandstop, band-reject or band-elemination (notch) filters are tuned circuits that prevent passage of signals within a specified band of frequencies. The specified frequency is the centre frequency, with performance specifications that include bandwidth, ripple, insertion loss and voltage standing-wave ratio.

Bandwidth is the range of frequencies that RF band-reject filters block with maximum attenuation. Ripple is the peak-to-peak variation of the passband response, and insertion loss is the total RF power transmission loss resulting from the insertion of a device into a transmission line.

Figure 4B (left) shows the amplitude spectrum of a

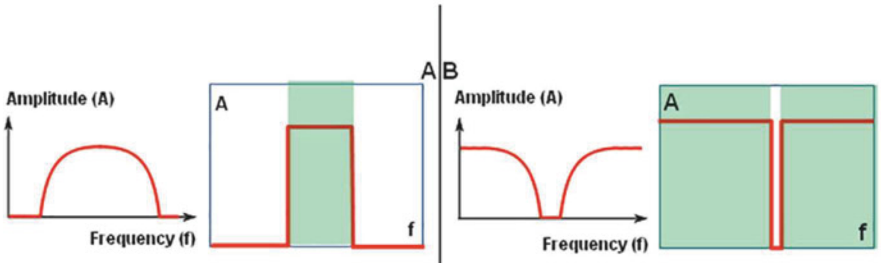

Figure 4: Amplitude spectra of: (A) bandpass; and (B) bandstop filters

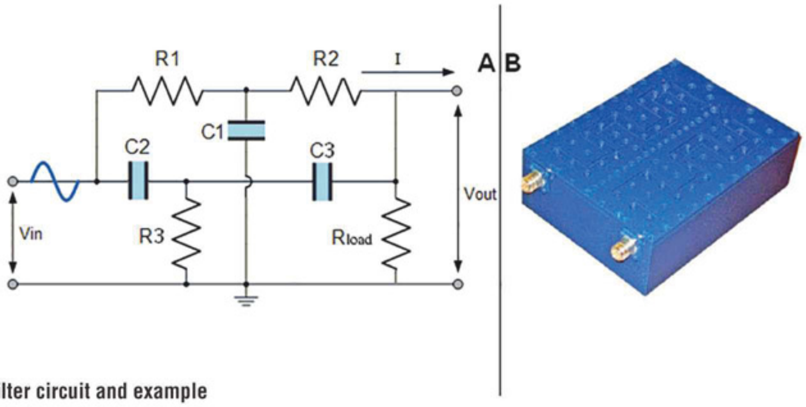

Figure 5: Bandstop filter circuit and example

bandstop filter with its parameters.

In signal processing, bandstop filters pass most frequencies unaltered, but attenuate those in a specific range to very low levels, see Figure 5A. The filter can be made of highpass and lowpass filters, just like the bandpass design, except this time the two sections are connected in parallel rather than series.

Figure 5B shows the small package size of a VHF-band bandstop filter from Reactel that rejects all frequencies between 240MHz and 270MHz by 60dB.

The lowpass section of a bandstop filter comprises R_1, R_2 and C_1 in a “T” configuration, and the highpass section comprises C_2, C_3 and R_3 also in a “T” configuration. Together, this arrangement is commonly known as a “Twin-T” filter, giving sharp response when the component values are chosen in the following ratios:

$$R_1 = R_2 = 2(R_3) \text{ and } C_2 = C_3 (0.5) C_1$$

Given these component ratios, the frequency of maximum rejection, known as “notch frequency” (NF) can be calculated as follows:

$$f_{NF} = 1/4\pi R_3 C_3$$

There are different mounting styles for RF bandstop filters, which use several types of connectors. Bandstop filters are used as telephone line noise reducers, in digital image processing and in many power amplification applications, such as electric guitars. They are also very useful in communications electronics for eliminating certain harmonics in signals and reducing interference.

Highpass Filters

A highpass filter allows high frequencies and rejects low ones, see Figure 6A. In this circuit arrangement, the reactance of the capacitor is very high at low frequencies; the capacitor acts like an open circuit, blocking any input signals until the cutoff frequency (f_C) is reached. Above f_C the reactance of the capacitor decreases sufficiently to act like a short circuit, allowing the entire input signal to pass directly to the output.

The f_C for a first-order highpass filter can be determined using the same equation as for a lowpass filter, while the equations for gain (A_V) and phase shift (φ) are modified slightly to account for the positive phase angle, as shown here:

$$A_V = V_{out}/V_{in};\ f_C = 1/4\pi RC;$$

$$\varphi = \arctan 1/4\pi fRC$$

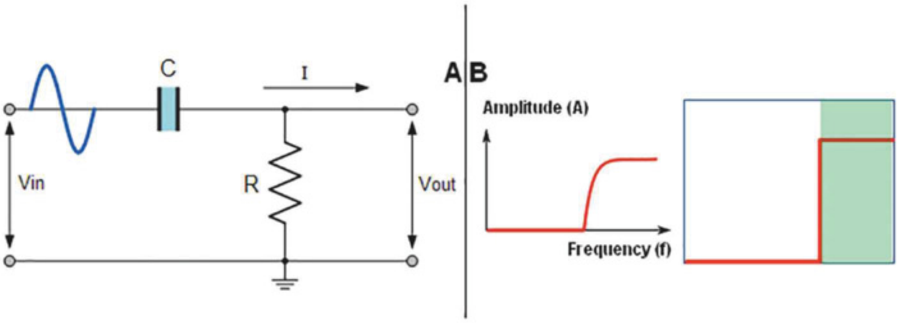

Figure 6: Highpass filter circuit and amplitude

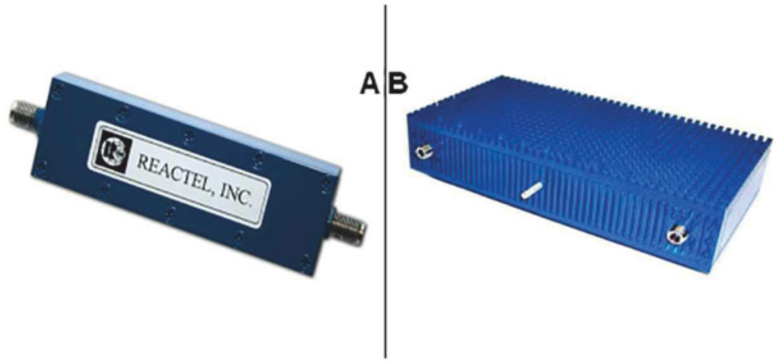

Figure 7: (A) Highpass; and (B) lowpass filter

This way, the signal is attenuated or damped at low frequencies with increasing output, whereas the lowpass filter only allows signals to pass below its cutoff frequency (f_C).

The actual amount of attenuation at each frequency varies from filter to filter. A highpass filter is usually modeled as a linear time-invariant system. It is sometimes called a low-cut filter or bass-cut filter.

Highpass filters have many uses, including blocking DC from circuits sensitive to non-zero average voltages, or RF devices. A highpass filter is often used to suppress acquisition noise.

Figure 6B (left) shows the amplitude spectrum of a highpass filter, with its parameters.

Figure 7A shows a wideband highpass filter with a passband of 18-40GHz, made by Reactel. This tiny unit is perfect for portable or "hi-rel" applications.

Lowpass Filters

Lowpass filters are the opposite of highpass filters, allowing low frequency signals and attenuating or reducing the amplitude of signals with frequencies higher than the cutoff frequency. In audio transmission applications they are also known as high-cut filters or treble-cut filters.

A simple passive RC lowpass filter can easily be made using a single resistor and a single capacitor in series, as shown in Figure 8A. In this arrangement the input signal is applied to the combination (resistor and capacitor in series) but the output signal (V_{out}) is taken across the capacitor only. This type of filter is generally known as a "first-order filter" or "one-pole filter", because there's only one reactive component in the circuit – the capacitor. Although this is an RC lowpass filter, it can also be called a frequency-variable voltage divider, using the following calculation of total resistance of the circuit (R_T) and the output voltage for two single resistors connected in series:

$$V_{out} = V_{in} \times R_2/R_1 + R_2, \text{ where } R_1 + R_2 = R_T$$

Lowpass filters exist in many different forms, and are used in audio applications and anti-aliasing filters to condition signals prior to analog-to-digital conversion. They can also be used for smoothing data, as acoustic barriers, for blurring images and so on.

Figure 8B (left) shows the amplitude spectrum of a lowpass filter with its parameters. Figure 7B shows a high-power lowpass filter made by Reactel, which passes the HF band with rejections to 500MHz, all the while withstanding power levels of 1250W. ●

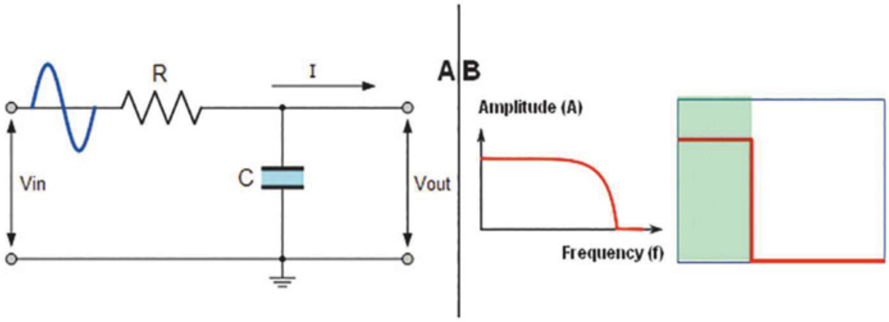

Figure 8: Lowpass filter circuit and parameters