RF Components Ebook

Essential Functions of RF Components in Radar Systems

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Radar systems have revolutionized the way we detect and track objects, becoming a cornerstone technology in defense, aerospace and various commercial applications. By transmitting short bursts of energy in the form of radio frequency (RF) and microwave signals, radar can pinpoint an object's location by analyzing the echoed signal reflected back from the object. These intricate systems rely on a variety of RF components working seamlessly together to deliver precise and reliable results.

At Knowles Precision Devices, we've spent decades solving complex challenges in the defense and aerospace industries. Our deep expertise in designing RF components, including capacitors, has earned us a reputation as a trusted problem solver.

In this eBook, we start by introducing the key functional components of radar and then dive into the inner workings of radar systems by looking closer at the jobs of the RF components behind key functional units.

Functional RF Components for Radar: Overview and Trends

Radar systems are designed to detect and identify an object's location. They use short bursts of energy to transmit RF and microwave signals and gather information from the echoed signal returned by the object.

Key Functional Components in Radar Systems

We can learn a lot about radar systems by looking at the functional components and what specific tasks they perform. In Figure 1, we treat each function as a separate block, even though these functions can be combined or divided across several circuits.

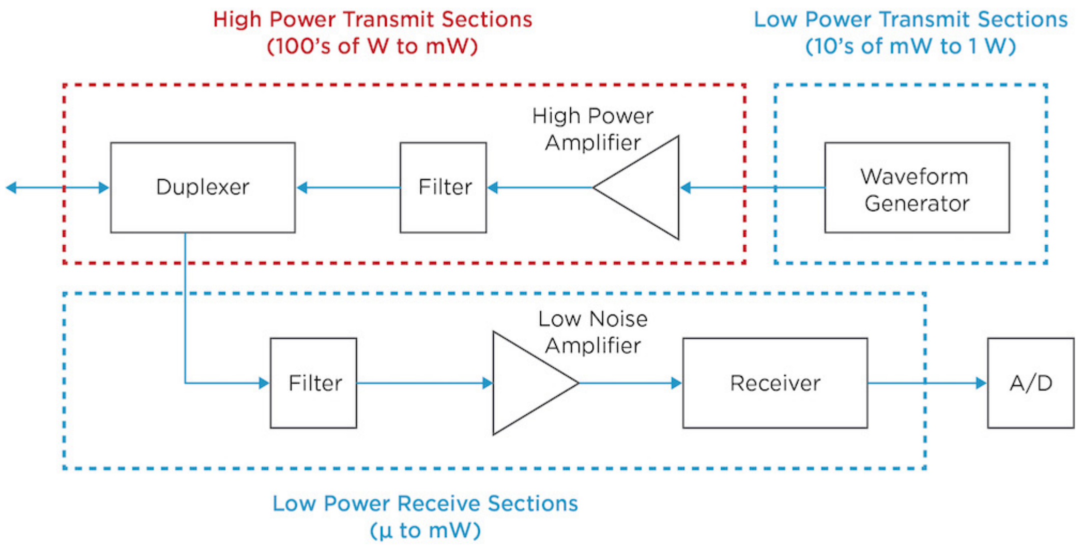


Figure 1. Functional components of a radar system.

Key functions in radar systems include:

Duplexing

A duplexer is tasked with ensuring that transmit and receive signals avoid collisions. T/R waveguide tube devices, circulators, filters and switches can all perform this task in different configurations. For example, in low-power T/R modules, a switch might be the preferred duplexer because they're small and easy to integrate.

Filtering

Radar systems can leverage filters on both the transmit and receive paths depending on the frequency of operation and bandwidth requirements of the system (Figure 2). Filters also play a key role in protecting data converters in direct sampling systems.

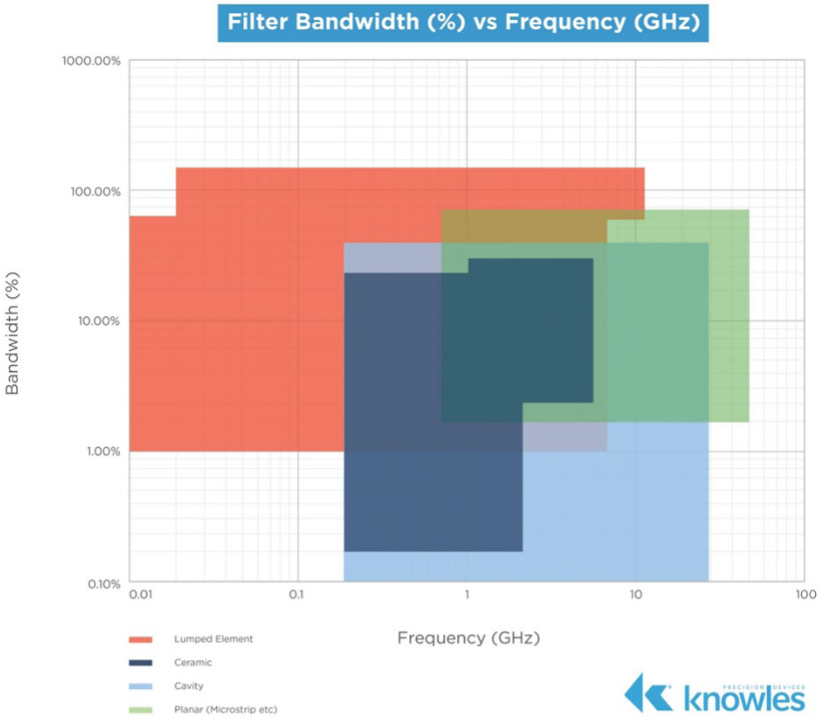


Figure 2. Filter bandwidth vs. frequency; in radar systems, filter selection depends on frequency of operation and bandwidth requirements.

Power Amplication

High-power amplifiers take signals from the waveform generator and increase their signal level to a higher power. Depending on the system, the increase could take the signal from hundreds of watts to megawatts. For example, PAVE PAWS was an early warning radar system and the first all-solid-state active electronically steered array (AESA) system. It had a transmit power of 340W per T/R module. Summed over 1,792 modules, the signal ended up at over 500 kW. High-power amplifiers usually leverage bypass capacitors, pulse storage capacitors and couplers.

Waveform Generation

Waveform generators create fairly low-power waveforms. These waveforms are pulsed or otherwise and modulated in frequency or phase as needed. Modern waveform generators are based on digital waveform generation (DWG) and are functionally similar to the arbitrary waveform generators (AWG) commonly found in an RF lab. Here, the desired waveform is expressed mathematically. Through direct digital synthesis (DDS), a digital-to-analog converter (DAC) can produce an analog signal from a digital input. In frequency synthesis, a low-phase noise oscillator with a small form factor is key.

Low Noise Amplification

Low-noise amplifiers (LNAs) amplify low-amplitude waveforms without decreasing their signal-to-noise ratio (SNR). A strong SNR improves the chances of detecting a target, so LNAs make it possible to detect these hard-to-find targets. Effectiveness is a measure of both resolution and accuracy. Accuracy improves as SNR increases. LNAs rely on bypass capacitors, bias networks and gain equalizers.

Receiving

Receivers are tasked with preparing input frequencies for the analog-to-digital converter (ADC). Depending on the frequencies and sensitivity requirements, one or more down conversion stages may be required. Each stage requires filtering, amplification and frequency conversion with the help of a low-phase noise frequency source.

Analog-to-Digital Conversion

The goal is to get the signal from the antenna into the ADC as directly as possible by removing RF components in its path. When the ADC input matches the RF frequency seen at the antenna, RF sampling and direct sampling become relevant. An RF-ADC's sampling rate, analog bandwidth, resolution and dynamic range help determine its ability to be used in RF sampling.

Phased Array Evolution

Radar plays a critical role in defense communications, law enforcement, space exploration, remote sensing and air traffic control. To accommodate different applications, these systems operate in a variety of frequency bands, including L, S, C, X and K bands. With high demand for multi-function, multi-mission systems, options like synthetic-aperture radar (SAR), featuring additional capabilities for imaging and tracking, are becoming more popular too.

The most recent transition, shifting the industry from subarray digital phased arrays to element-level digital arrays, demonstrates some key benefits (Figure 3). We're seeing more flexibility of mode and bandwidth, and when each element in the array has its own ADC, there's an inherent increase in SNR.

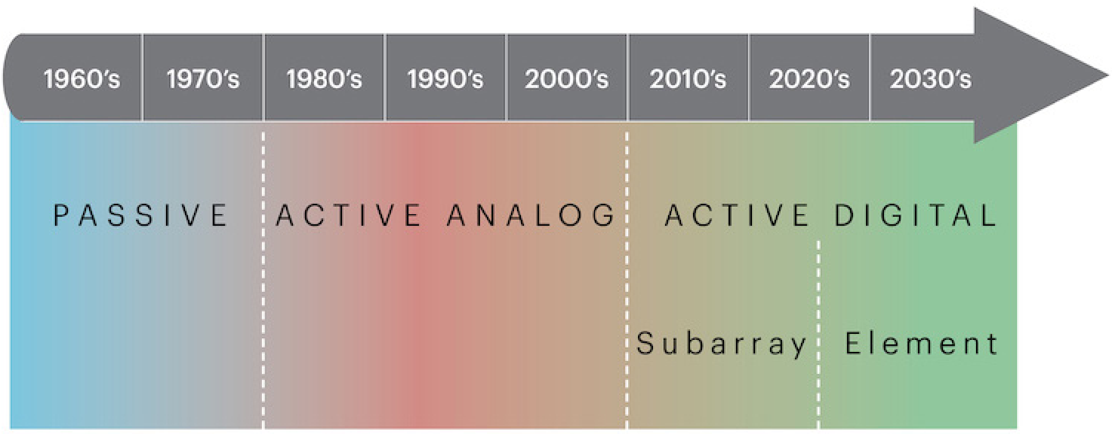


Figure 3. The technical evolution of radar.

The evolution can be observed in block diagrams in Figure 4:

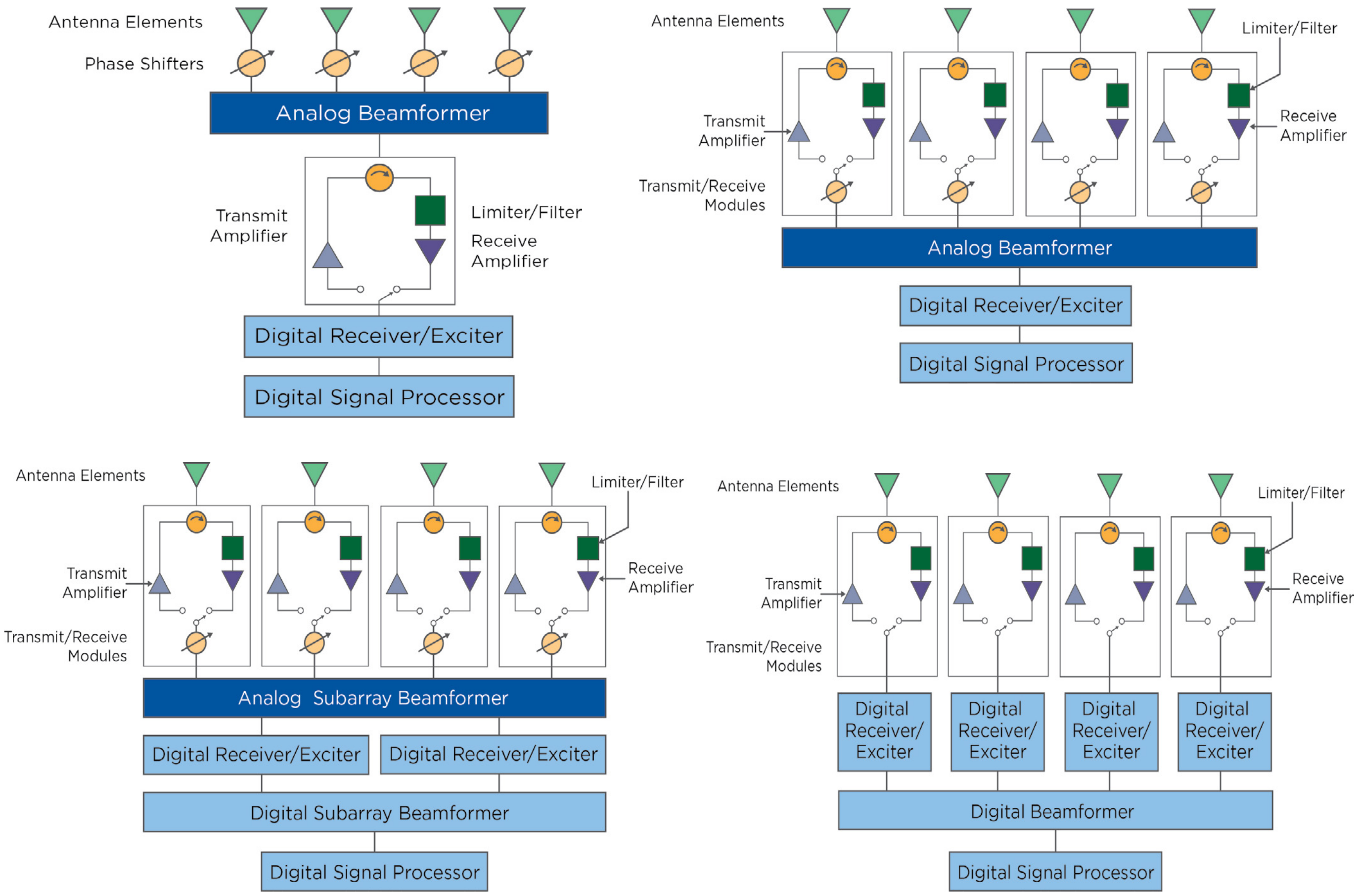


Figure 4. The evolution of radar systems as block diagrams, including passive phased arrays (top left), active phased arrays (top right), subarray digital phased arrays (bottom left) and element-level digital phased arrays (bottom right).

The Expansion of Digital Architecture

With advancements in adjacent areas like RF and digital electronics, digital arrays are applicable in a wider variety of systems. Considering that these technologies build on each other, a digital-array radar is built on the fundamentals of a phased array antenna; however, in fully digital arrays, transmitted and received energy can be digitized at the element level. Digital-array radar can form multiple receive beams simultaneously. The number of beams, instantaneous bandwidth and dynamic range are only limited by the data converters, digital hardware specifications and power consumption.

As the industry expands on the capabilities of RF-ADCs in terms of analog bandwidth and sampling frequency, every-element DREX circuits are starting to emerge. This places fast converters close to the antenna and encourages the development of high-rejection filters to protect receivers.

Functional RF Components Deep Dive: Duplexing in Radar

As mentioned above, duplexing is a crucial function in radar systems, allowing for the transmission and reception of signals on the same antenna without interference. There are two main approaches to duplexing in modern radar systems. One leverages a circulator and a hybrid coupler. The other uses a single pole double throw switch (SPDT).

Circulator and Hybrid Coupler vs. SPDT

In radar systems with a traditional Tx/Rx antenna, duplexers separate Tx/Rx signals during operation, allowing the antenna to be used for transmitting and receiving signals. This function is particularly important for maintaining performance in high-power radar systems.

Using a circulator, limiter and an SPDT switch, Tx/Rx signals can be kept separate yet connected to the same antenna (Figure 5).

In this case, the circulator directs transmit energy to the antenna and isolates the transmitter from input energy. Hybrid couplers and limiters join forces to protect the receiver by directing reflected transmit energy and unwanted input energy to a load for dissipation.

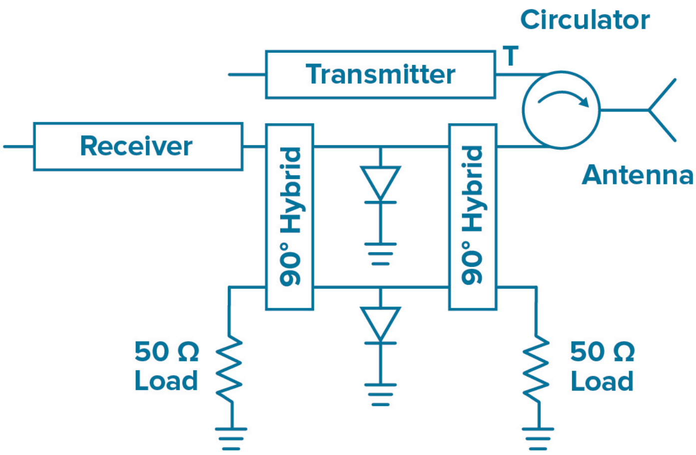


Figure 5. Circulator and hybrid coupler duplexing scheme.

Thermal design considerations are particularly important for 90° input couplers. Excessive heat caused by power dissipation can destroy these resistors or change their resistance values. If either of these conditions occurs, the mismatched load will reflect power back into the coupler because the resistors won't be able to terminate limiter reflections. Knowles Precision Devices tests couplers over temperature to avoid this potential pitfall.

Relying on an SPDT switch and limiter to protect the received signal requires fast, robust power switches. Here, the switch directs energy from the transmitter to the antenna and then to the receiver. The limiter helps protect the receiver (Figure 6).

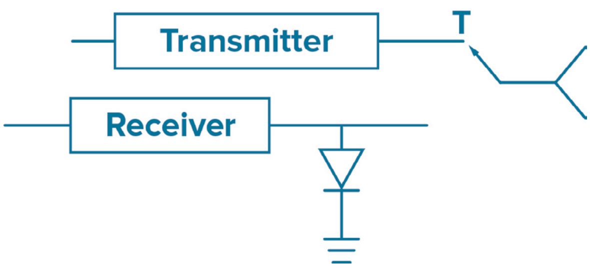


Figure 6. SPDT duplexing scheme.

T/R modules are an essential component of AESAs. These modules provide a high-power transmit path and a sensitive receive path to interface directly with a radiating element. Paths either operate using a parallel structure with elements designed to isolate and direct signals, like circulators and limiters, or using a time-multiplexed technique with solid-state switches, Figure 7.

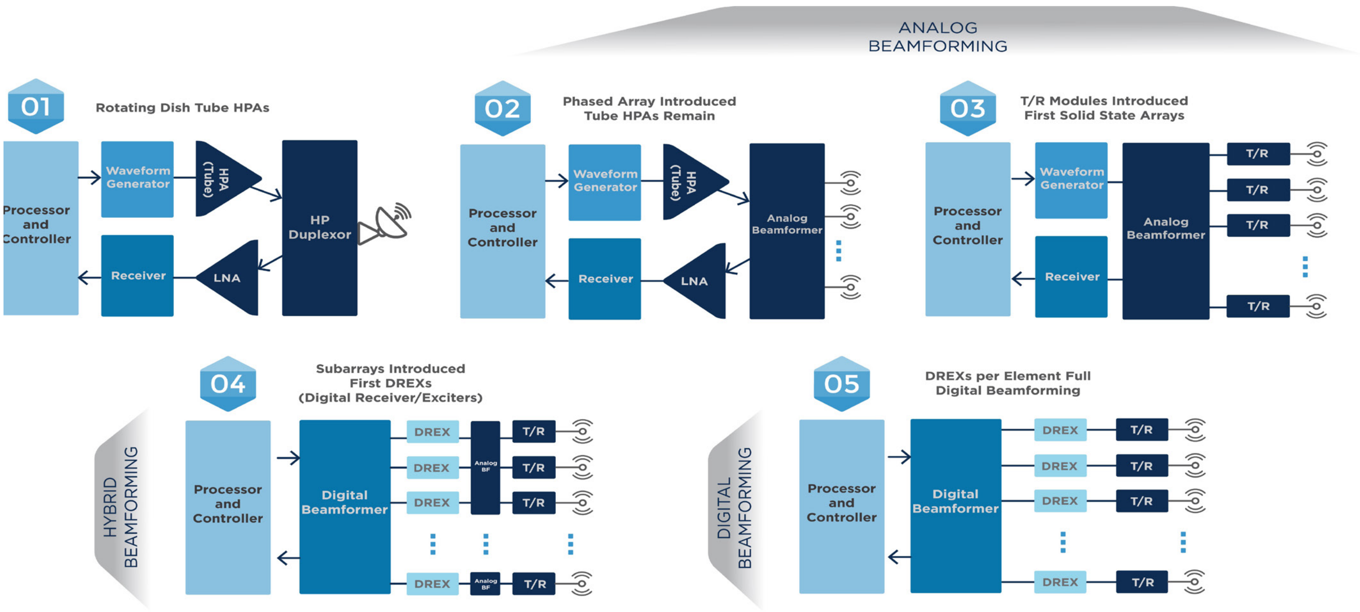


Figure 7. Antenna development milestones in the journey from analog to digital.

The Evolution of T/R Modules and High-Power GaN RF Switches

T/R modules appeared on the scene in the 1980s. As these modules evolved alongside radar system development, beamforming best practices have too. Today, duplexing, Figure 8, is still an important function in a digital beamforming array.

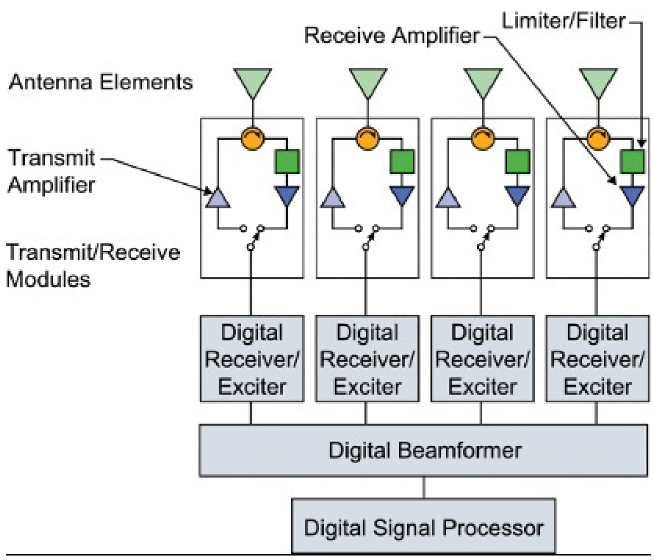


Figure 8. Duplexing is diagrammed as a circulator and takes place in each T/R module.

Since they're more widely available, gallium nitride (GaN) technology is an option for robust LNAs, not just power amplifiers. With a GaN-LNA, there's no need for a limiter, and with a GaN high-power SPDT switch, the circulator can be replaced with something less bulky. These changes, shown in Figure 9, reduce the area in the front end of the module, minimize complexity and economize assembly costs.

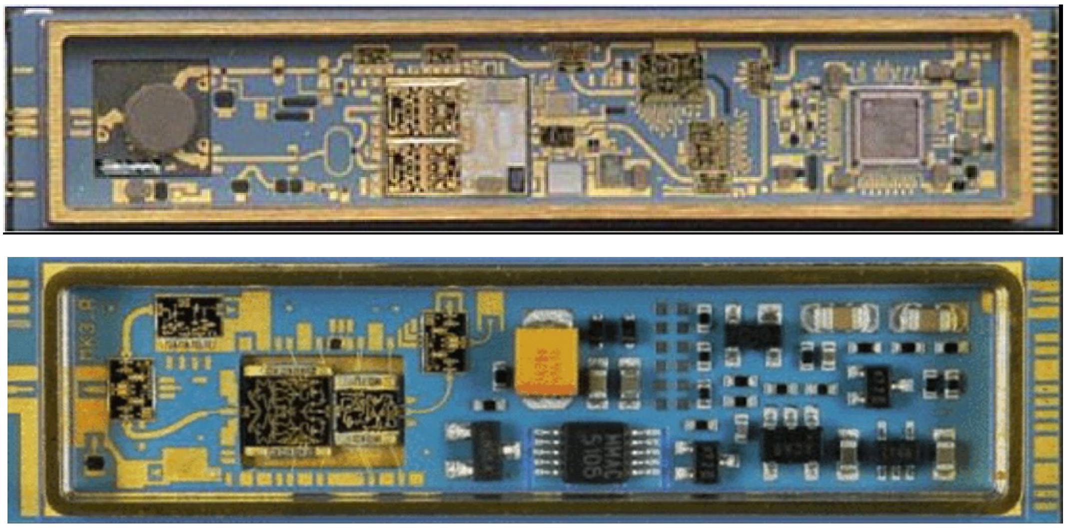


Figure 9. GaN-based T/R module with a circulator for duplexing (top) vs. upgrading to a switch for duplexing (bottom). Source.

Monolithic microwave integrated circuit (MMIC) devices, Figure 10, rely on passive components, like bias networks and decoupling capacitors, to ensure proper operations. The SPDT can be integrated into a single T/R module MMIC, but more passive components are required to support additional functionality. For example, a typical T/R module requires bias and control line networks. Depending on your approach to duplexing, Knowles Precision Devices would support your system with hybrid couplers, bias networks or both.

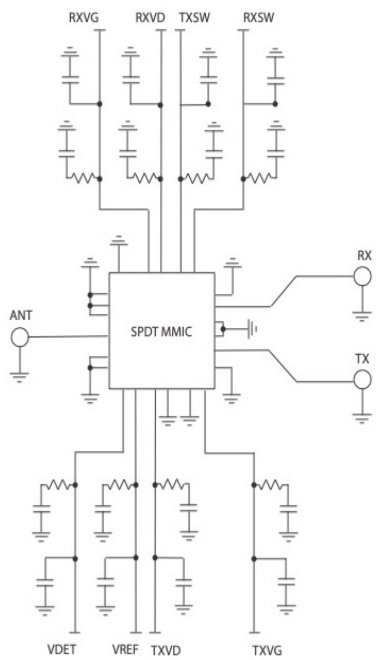


Figure 10. A diagram of a MMIC device.

Functional RF Components Deep Dive: Filters in Radar

In general, filters are responsible for solving a variety of problems in the radar receiver. You can think of a filter as the problem-solving assistant in the system that comes along and tidies up different messes that are either outside the radar or made by components in the radar itself. Take a look at the radar functions diagram we discussed earlier in this ebook (Figure 1) and think about the receiver.

A typical heterodyne receiver has several filter jobs that need to be done, depending on the problems that need to be solved/messes that need to be cleaned up (Figure 11). Let's take a closer look at these problems and the filtering technology that can be used to solve them.

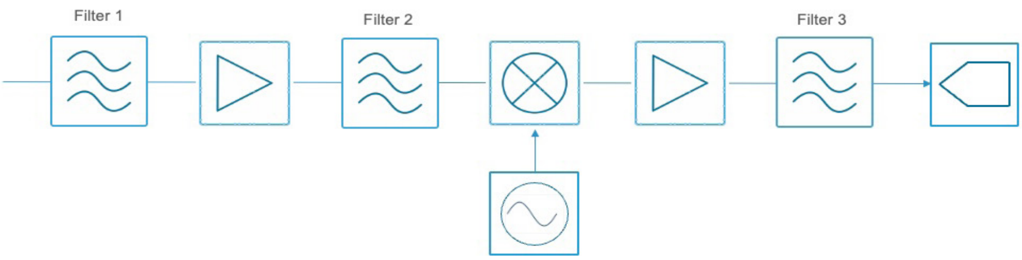


Figure 11. A diagram of a heterodyne receiver.

Solving Signal Problems in a Radar Receiver with Filtering

In the radar receiver, the first problem that must be solved is selecting the band of interest and removing any signals outside the band of interest that would confuse or overwhelm the receiver—this is what the first filter must take care of. The second problem to be solved is to remove any signals close enough to the band of interest that exist at mixer image. The second filter takes care of these mixer related messes.

The third set of problems arises when we get to the ADC. Here, we need to remove any messes made by the amplifier and ensure the ADC only "sees" the correct alias band. A high-rejection filter close to the ADC can take care of this. In the case of the heterodyne approach, this job can be made easier by making the intermediate frequency (IF) fall well below the ADC's Nyquist limit, which defines the maximum frequency that can be accurately captured and represented without distortion when using a specific sampling rate.

With recent ADC technology innovations, it is now possible to perform direct sampling up to X band frequencies, depending on the sensitivity required. Since direct sampling digitizes signals directly, the mixer and some of the amplifiers in the receiver can be removed, eliminating some of the messes the filters need to clean up (Figure 12).

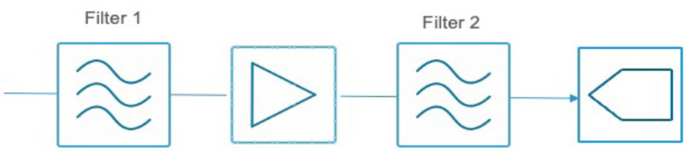


Figure 12. An example of a direct sampling receiver.

With a direct sampling receiver in place, we're left with problem one (i.e., selecting the correct band of interest and removing out of band interference) and problem three (i.e., cleaning up the interference generated by the amplifier and selecting the alias bands of the ADC). We've effectively eliminated problem two. Depending on the performance required in the receiver, and the RF input to the ADC, a high rejection level may be required to achieve this. For example, in an X band direct sampling system, you may see a broadband, low-loss and high-rejection filter such as our B096QC2S in this role.

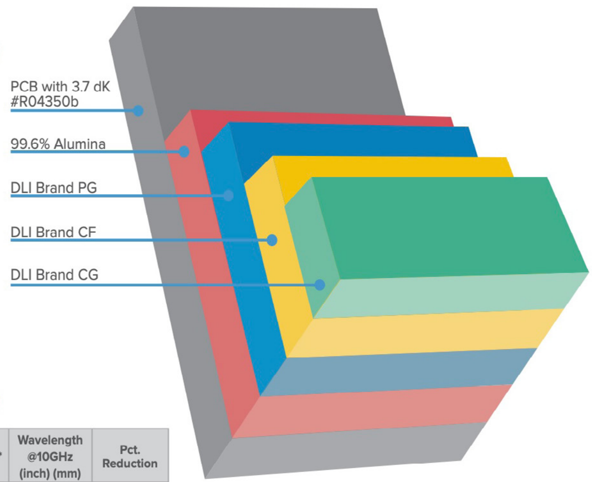
As direct sampling receivers evolve, fully digital beamforming becomes realistic at some of the key radar bands such as S and X and eventually Ka. Knowles Precision Devices' filter technology is rapidly advancing to keep pace with these possibilities.

Switch Filter Banks for Agile RF Receiver Design

Since modern radar systems are expected to serve in a multi-mission capacity, tunable bandwidth is becoming more and more desirable. Designers need to be able to balance radar range and resolution and optimize performance across missions. Further, these systems need to operate reliably in a congested spectrum where there are many blockers.

In RF communications systems, unwanted input signals, otherwise known as blockers, directly or indirectly degrade the gain and SNR of the signal of interest. Blockers take the form of intentional and unintentional interference. Other RF communications systems operating in the adjacent frequency spectrum can cause unintentional interference, but so can malicious EW systems.

Relative Filter Size
Compared by Material



Filter Characteristics
Compared by Material

Material	dK	Effective K**	Wavelength @10GHz (inch) (mm)	Pct. Reduction
PCB with Dk #R04350b	3.7	2.8	0.707 [17.96]	------------
99.6% Alumina	9.6	6.5	0.462 [11.73]	34.7%
DLI Brand PG	12.5	8.2	0.412 [10.46]	41.7%
DLI Brand CF	25	15.1	0.304 [7.72]	57.0%
DLI Brand CG	67	36.8	0.194 [4.93]	72.6%

**Values are for Freq. 10GHz on 0.010" Substrate

Figure 13: Relative DLI brand filter size with materials breakdown.

Agile RF receivers can be optimized moment-to-moment to adjust to evolving parameters. This level of control is accomplished using fully digital receivers with analog filter protection to evade blockers and prevent receiver damage. Nimble analog RF components, like switch filter banks, are critical to accomplish this level of optimization.

Switch filter banks are traditionally associated with larger footprints, but Knowles Precision Devices is leveraging materials science innovations to shrink the size of each individual filter. We use high-precision lithographic processes to pattern microstrip filters on our custom ceramics, and we develop low-loss, temperature-stable dielectrics that allow us to significantly reduce filter form factors (Figure 13).

From there, our engineering team uses these miniature filters to create state-of-the-art, multi-band filter structures that enable tiny switch filter banks.

Beyond miniaturizing filter components, there's an opportunity to innovate around packaging. In partnership with Criteria Labs, we've established a small but reliable packaging concept for switch filter banks (Figure 14). With consideration for input size and how narrow the output needs to be, a designer has room for more channels.

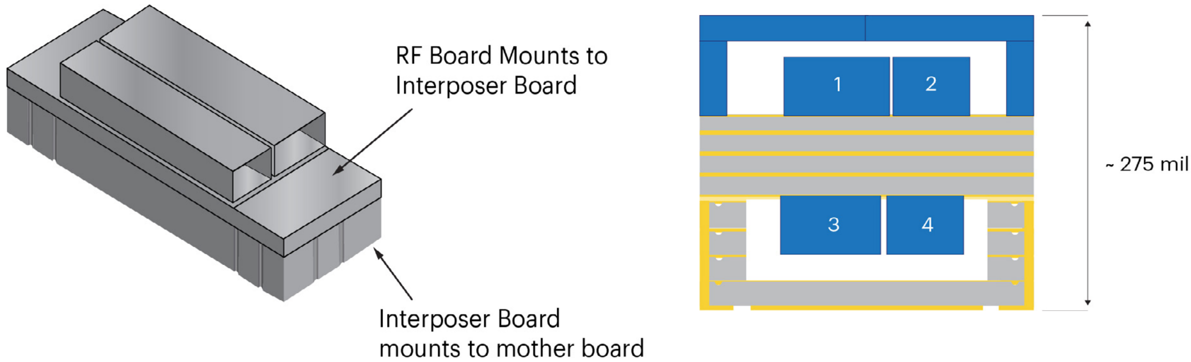


Figure 14. Knowles Precision Devices and Criteria Labs collaborated on a design to shrink a four-channel switch filter bank.

The design, based on a four-channel filter bank, features a 3D-stacked structure with alternating filters and interposer boards mounted directly to the printed circuit board (PCB). The result is a reduction in internal spacing that ultimately reduces the size of the filter bank.

The Influence of Phase in Filters for Radar

Characterizing phase is an important, and often overlooked, aspect of assessing filter performance. Phase performance can be described in several different ways, including:

Phase Linearity

Also known as group delay, phase linearity describes how the phase of the frequency components of a signal change in relation to the frequency itself. Conceptually, group delay is the negative derivative of the phase of a signal in relation to angular frequency. Since real-world operating conditions aren't ideal, variations over frequency are expected. Within a small bandwidth, group delay remains near-constant. In many applications, flat group delay is a desirable characteristic, so it's best to select filters with a linear phase response.

When steering a beam in a phased array, phase settings that are independent of frequency help maintain the correct beam position, even when frequencies shift. For example, in image processing or digital data transmission, filters with a linear phase response maintain the signal's wave shape and avoid phase distortion, since all frequency components experience the same amount of delay.

Phase Stability Across a Range of Temperatures

Radar leverages electromagnetic energy to accurately measure distances. The frequency content of radar pulses can span upwards of one gigahertz of bandwidth. Pulses must be treated the same across that bandwidth or you can expect distortion to cause inaccuracies in radar range measurements.

The flatness of group delay over temperature is particularly important in phased array systems and SAR, which is used for creating high-resolution images of the surface of the earth and other planets. In addition to more accurate measurements, minimizing phase variability over temperature reduces calibration requirements.

Phase Length Repeatability

Along with the flatness of group delay, consistency—over variables like temperature and frequency—is important in scenarios where achieving an appropriate null depth involves amplitude and phase tracking. Consistency and repeatability positively contribute to signal coherence, image quality and measurement accuracy.

Temperature-stable ceramics and precision thin film processes can minimize phase variation over temperature and drive repeatability in phase and frequency metrics from part to part and batch to batch. At Knowles Precision Devices, we measure phase over environmental conditions as part of our acceptance test protocol (ATP) for all custom filters to ensure a high-quality product.

Functional RF Components Deep Dive: Gain Equalizers in Radar

LNAs in RF receivers are designed to amplify low-amplitude signals (i.e., less than -100 dBm) from an antenna without decreasing their SNR. In radar applications, a strong SNR increases the likelihood of detecting a target, so LNAs play an important functional role. Effective targeting requires both high resolution and high accuracy. A strong SNR translates to high accuracy.

To accommodate the performance demands and size constraints of phased-array radar systems and receive those signals of interest, LNAs must generate very low noise and deliver high gain. That said, this is a challenging combination of design specifications. Engineers must consider effective power limiting, thermal compensation and frequency equalization over a wide bandwidth.

Optimizing RF Performance with Integrated Gain Equalization

RF amplifiers can produce uneven gain across a device's operational bandwidth, causing distortion and other undesirable effects. Frequency equalization requires introducing a positive gain slope to the system to compensate for the natural gain roll-off in most wideband RF amplifiers. Incorporating gain equalization directly into the amplifier design through integrated components allows engineers to simplify the design (e.g., remove discrete resistors and capacitors). The uncompensated gain slope and the number of gain equalizers needed to produce an even gain depend on the amplifier. You can combine equalizers to achieve the gain slope that's appropriate for your application.

Passive gain equalizers are best suited for low-noise amplifier designs because of their compact form and lack of direct current (DC) power and control signal requirements. With a monolithic construction, precision thin-film conductor technology and resistor films with proprietary high dielectric constant ceramics, Knowles' DLI brand gain equalizers offer excellent RF performance and repeatability.

Capacitor Support for RF Functions in Radar

Capacitors are essential components in radar systems, playing critical roles in power amplification, signal conditioning and maintaining pulse integrity. Whether it's supporting solid-state power amplifiers or ensuring efficient bypassing for amplification, capacitors help meet the rigorous demands of modern radar applications. In this section, we will explore how capacitors contribute to various RF functions in radar, focusing on their roles in charge storage, matching networks and signal stabilization to optimize system performance.

Capacitor Support in Power Amplification

For many RF applications, power amplifiers (PAs) are based on traveling wave tube (TWT) technology, which uses electron beams in a vacuum to achieve high power levels. However, this type of PA can be quite heavy, large and inefficient, making it challenging to use in size-constrained environments or when precision is required.

Instead, solid-state power amplifiers (SSPAs), which are based on modern semiconductor devices like transistors developed with GaN or gallium arsenide (GaAs), are generally smaller, lighter, more compact and offer higher reliability. Therefore, SSPAs can be used to maximize system performance in applications where size, efficiency and reliability are critical such as satellite communications or many radar systems.

To achieve a higher overall power output efficiently, SSPAs are typically designed using power summation over a series of modules, which provides a graceful degradation capability not found with TWTs. Thus, a basic building block of many all-solid-state HPAs is the PA module (Figure 15).

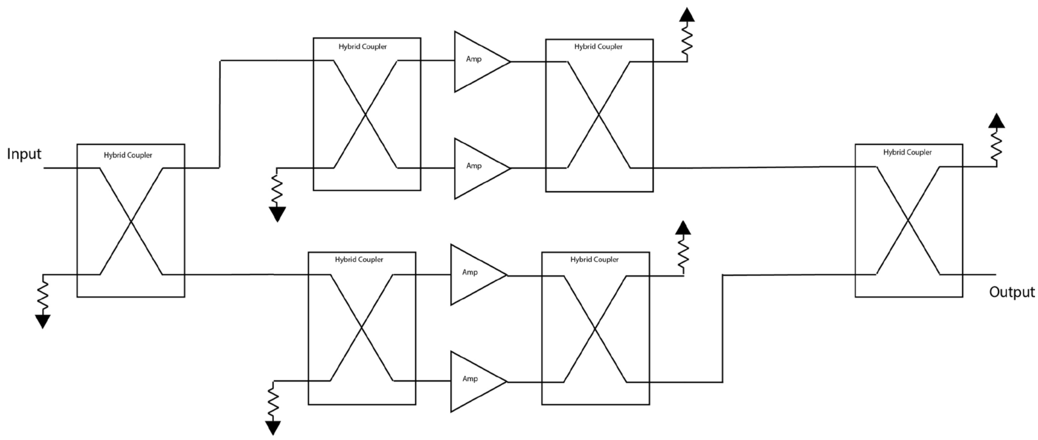


Figure 15. An example of a single PA module.

In the example shown in Figure 16, the input to the HPA is split four ways and passed through four PA modules. Then, the amplified output from each PA module is combined with a four-way combiner.

In radar systems, PAs serve an essential role in transmitting signals that probe the environment of interest. They boost signal strength and maintain its quality to achieve the intended range and resolution of the overall system.

PAs need several types of capacitors to do their jobs. Here are the main circuit locations (Figure 17) where you'll find capacitors supporting amplifiers.

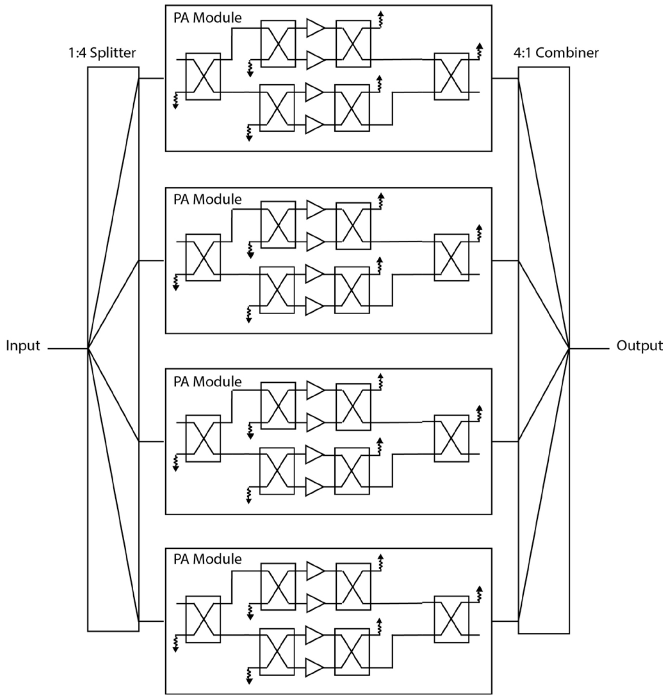


Figure 16. A full view of an HPA with four PA modules.

Input/Output Matching and Coupling

Matching ensures that the input and output impedance of an amplifier aligns with the rest of the circuit. In LC matching, inductors (L) and capacitors (C) form networks that facilitate impedance matching between different parts of a circuit to maximize power transfer and minimize echoes in RF applications.

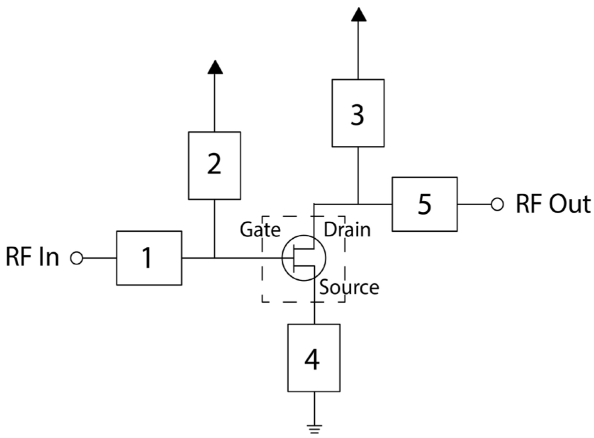


Figure 17. Example of the five key circuit locations where capacitors support power amplification.

Depending on your application requirements, LC matching networks can be configured a few different ways, shown in Figure 18, to accommodate various operating frequencies and impedance levels:

- **L-Network:** Includes an inductor and a capacitor in series or in parallel, depending on whether the impedance needs to be stepped up or down. L-networks are most effective in narrow frequency bands as they don't allow for much adjustment.
- **Pi-Networks:** Form the Greek letter "Pi" with two capacitors and one inductor. They're designed to transform a low source impedance to a high load impedance or vice versa, so they're particularly useful in power amplifiers and RF amplifiers.

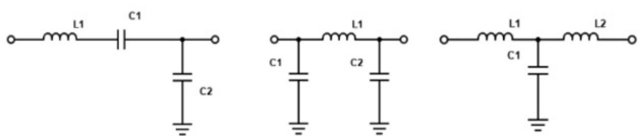


Figure 18. Bandpass L network (left), Pi network (middle) and lowpass T network (right).

- **T-Network:** Includes two inductors and one capacitor (or two capacitors and one inductor) to form a T-shaped configuration. With greater versatility, T-networks can manage a wider range of impedance values compared to L-networks.

While many amplifier MMICs come equipped with matching capabilities, these networks of discrete and distributed elements support finer performance optimizations.

Coupling

Coupling describes the linking between different stages of a circuit to ensure effective signal transfer and strong system performance. In radar systems, the way components are coupled can significantly impact signal integrity and power efficiency. With capacitors in series, AC coupling (i.e., DC blocking) connects circuit stages such that only AC signals, like RF or microwave signals, pass from one stage to the next. By extension, this removes any DC offset and protects components by allowing chips with different common mode voltages to interface with each other. Amplifier MMICs can also come with their own coupling, but circuit designers are largely responsible for coupling in high-performance systems.

Bias Networks

Biasing ensures that the right amount of DC voltage and current goes to an active device (e.g., field-effect transistor (FET)) to keep it operating in an optimal region.

An active device can also connect to a gate, drain or source bias network. Gate bias networks control voltage at the gate terminal of an FET, relative to its source, to act as a switch in digital applications or a set point for analog applications. Drain bias networks set and control voltage at the drain terminal of an FET, which influences the output characteristics. Source bias networks adjust voltage and current at the source terminal for added stability. Bias networks are critical for setting the quiescent current to optimize amplifier performance metrics like linearity and efficiency.

Bypass capacitors and storage capacitors connect to bias networks and contribute to the stability and efficiency of the amplifier circuit (Figure 19). Bypass capacitors act as lowpass filters, allowing DC signal through while removing low- and high-frequency RF noise and interference that could negatively impact the amplifier. Larger capacitance is helpful for low-frequency filtering and smaller capacitance is best suited for higher-frequency RF signals.

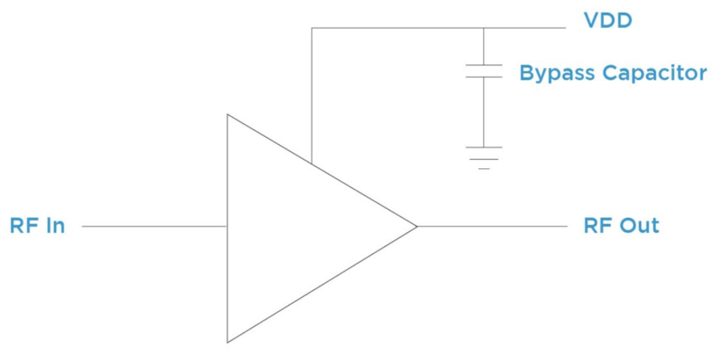


Figure 19. Example of a bypass capacitor that provides an efficient path to ground for RF energy.

Large charge storage capacitors can maintain power levels during pulsed operation (Figure 20). Aluminum electrolytic capacitors, for example, make great storage capacitors because of their high capacitance density. They're often found in or near the T/R module and the pulse driver circuitry in a radar system.

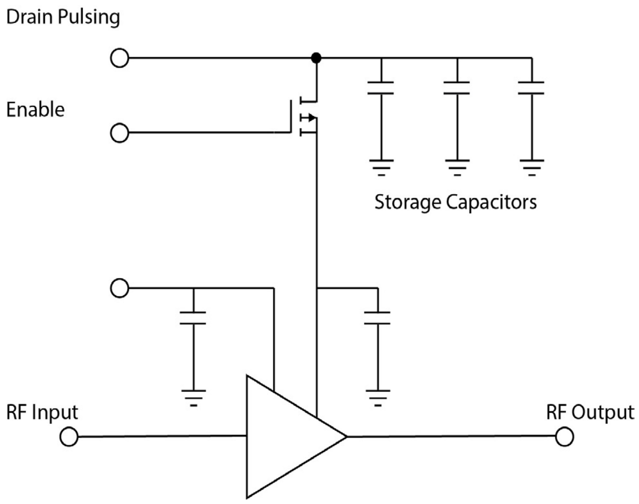


Figure 20. Example of power amplification circuit with storage capacitors.

From signal conditioning to stability and noise reduction, capacitors support a variety of critical functions in power amplification within radar systems. As these systems grow more and more complex, component-level decisions have a more significant impact on performance.

The Role of Couplers, Combiners and Dividers in the SSPA

When it is necessary to deliver a high level of output power to the antenna, power combiners and dividers are key components needed in the transmitters. Let's take a closer look at how these components function.

RF power dividers are designed to split an incoming signal into multiple outputs such that there's a portion of the original signal's power in each output. These signals are then fed into multiple amplifiers, where each module amplifies a portion of the signal, making it possible to achieve a higher overall power level when the output of the modules is combined again. This is where the power combiners come in, bringing the split signal back into single high-power RF signal that is then transmitted through the radar's antenna.

Couplers, such as quadrature hybrid couplers, can be used to perform the power splitting or combining while providing improved input match for unbalanced loads. Using a quadrature hybrid coupler for these functions can offer many benefits such as balanced amplification, enhanced signal linearity and isolation between amplifier modules, which will lead to more efficient and stable RF systems.

Capacitor Support in Charge Storage for Power Amplification

To adapt to the growing number of threats facing radar systems and support the transition to fully digital arrays, power amplifier modules must be designed to fit in smaller and smaller spaces. From functions like signal conditioning to noise reduction, capacitors support many critical functions in power amplification within radar systems, and the challenge is to get the capacitance required for charge storage within the space allotted.

Achieving the appropriate capacitance often requires a bank of low-profile, surface-mount capacitors, which can consume board space and create self-heating "islands" in the middle of the bank.

Capacitor Support in Maintaining Pulse Integrity

In radar systems, pulse compression improves range resolution and SNR, so it's advantageous, but it introduces other challenges like maintaining the integrity of pulses in the signal chain. Large storage capacitors, usually positioned near the power supply or in a nearby control board, maintain the voltage generated by the source during pulsed operation (Figure 20). Aluminum electrolytic capacitors make excellent storage capacitors because of their high capacitance density. Their presence relieves the switch regulator of handling a higher power load and reduces pulse droop.

Pulse droop describes the decrease in amplitude of a pulse over its duration, which translates to radar range and can affect the accuracy and effectiveness of a radar system. In radar, the challenge is to implement charge storage effectively while evading space constraints and pitfalls like this.

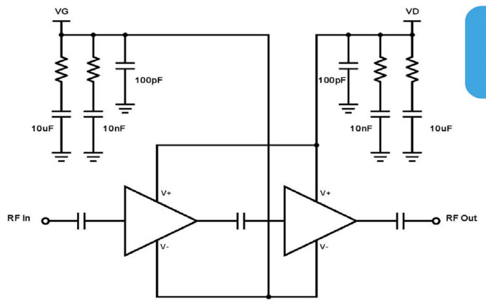
Capacitor Support in Bypassing for Amplification

MMIC amplifiers are widely used in defense radar systems. The industry recognizes them as a compact, high-performance option that's reliable and easy to integrate. Whether they serve a receive (e.g., LNA) or transmit (e.g., PA) function, MMIC amplifiers rely on bypass capacitors to perform their core function to amplify microwave signals.

When placed in parallel with the signal path, capacitors serve a bypassing function. They allow DC to continue along the wire, but they divert high-frequency signal components to ground (i.e., shunt to ground). In other words, capacitors act as low-pass filters that prevent RF noise from feeding back to the amplifier and minimize interference by decoupling the circuit and the supply.

A range of frequencies must be removed from DC lines, so naturally, there's a range of capacitor values to accommodate that. For example, Figure 21 shows a PA gate and drain bias circuit leveraging three different bypass capacitor values.

Larger capacitance values typically serve in low-frequency filtering applications and smaller capacitance values are best for RF applications; however, certain bypass capacitors support a wide range of frequencies and device technologies.



- 10µF (low pass to 16kHz at 1Ω)
- 10nF (low pass to 16MHz at 1Ω)
- 100pF (low pass to 1.6GHz at 1Ω)

Figure 21: Example of a power amplifier's gate and drain bias circuit transistor configuration.

Many capacitor types, from electrolytic to ceramic NPO, can function in a bypassing capacity, so your selections depend on your system's frequency response and stability requirements. Aside from observing the general rule of thumb that the impedance of your bypass capacitor should be valued at 10 percent of the impedance of the relevant circuit element, consider factors like insulation resistance (IR), equivalent series inductance (ESL) and equivalent series resistance (ESR).

Single-layer bypass capacitors (SLCs) can support a wide range of frequencies and bypassing close to MMIC chips. That proximity is critical for avoiding the stray inductance caused by a long trace. Knowles Precision Devices' single-layer vertical electrode capacitor series (V Series) includes a 100nF V80 bypass capacitor with an operating voltage of 50V in a .084" x .042" package.

Optimized Capacitor Solutions from Knowles Precision Devices

Knowles Precision Devices is a trusted problem solver with decades of experience serving the defense and aerospace industries. Our capacitors are designed with size, weight and power (SWAP) in mind, and we use vertical integration to provide high-performance components for your unique circuit challenge. Balancing energy density, temperature rise, reliability, and construction for radar applications takes a deep understanding of component and material specifications. Knowles Precision Devices is committed to supporting you as you work through your design constraints.

Author

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Peter Matthews is the Director of Technical Marketing at Knowles Precision Devices. As a division of Knowles Corporation, Knowles Precision Devices (KPD) focuses on production of a wide variety of highly engineered capacitors and microwave to millimeter-wave components for use in critical applications in military, medical, electric vehicle, and 5G market segments. Peter has over 20 years of experience in technology sales, marketing, and product management.

If you need help selecting from our portfolio please contact us and we can guide you through the selection process.