WHITEPAPER

Reduce Cost and Complexity in 5G mmWave systems with Surface Mount Solderable Filter Components

Introduction

Frequencies in the mmWave spectrum will play a key role in 5G communications. RF technology that was developed around existing mmWave applications has evolved to encompass the needs of 5G wireless access. Components for such systems need to be selected for performance and cost – commercial systems are subject to intense price pressure and so both the purchase cost and the implementation cost of a component become important factors in selecting devices for a new design.

SMD packaging to control cost

The price of the devices themselves are only one part of a designs overall cost. The ability of the component to fit into standard assembly processes such as SMD lead free pick and place manufacturing is an important factor to consider. The Hybrid approach of combining surface mount with chip and wire assembly could prove to be a cost driver, since the assembly needs to take place in clean room environments and can result in performance variation from assembly that requires follow up tuning. By choosing all SMD packaging the manufacturers of millimeter wave systems can use standard assembly lines, and will avoid the need for expensive die attachment and wire bonding tools in clean room environments.

The question then becomes that of the availability of the necessary devices in surface mount packaging. Mass market consumer wireless products have pushed the development of low cost packaging technologies suitable for RF frequencies. With the growing market for SMD RF packages there was a need for size reduction that reduced the impact of package parasitics, enabling an increase in the maximum operating frequency of SMD packaged ICs. In Automotive Applications for example mmWave frequencies find application in radar based Advanced Driver Assistance Systems (ADAS), helping drivers control vehicles and to assist in automated functions. These systems often use both short range (at 24 GHz) and long range (at 77 GHz) radar to scan the environment around the car. The transceivers are packaged in SMD packages to allow the use of standard production equipment in manufacturing of these systems.

5G mmWave Radio Architectures

When it comes to addressing the cost effective assembly of 5G mmWave systems a good place to start would be to consider the kinds radio architectures that are being deployed and then ask ourselves what device packaging looks like for the major block diagram components.

The standard choices for implementing Full Duplex communications that can influence radio architecture has been between Frequency Domain Duplex (FDD) and Time Domain Duplex (TDD). For 5G systems operating < 6GHz both FDD and TDD each have their own benefits. At mmWave frequencies though TDD is generally recognized as the preferred approach because: 1, Both Transmit and Receive signals are at the same frequency, making adjustments to propagation and fading characteristics somewhat simpler. 2, TDD provides improved utilization of wider bandwidths and 3, Technologies like massive MIMO that are seen as essential to 5G are easier to implement with TDD.

Time Domain Duplex Architectures

An approach to implementing TDD is with a T/R switch close a common antenna that is used for both Transmit and Receive signals. The T/R switch alternates between the radios Transmit and Receive modes, routing signals between each path as necessary. Figures 1 and 2 illustrate a simplified view of a TDD radios architecture

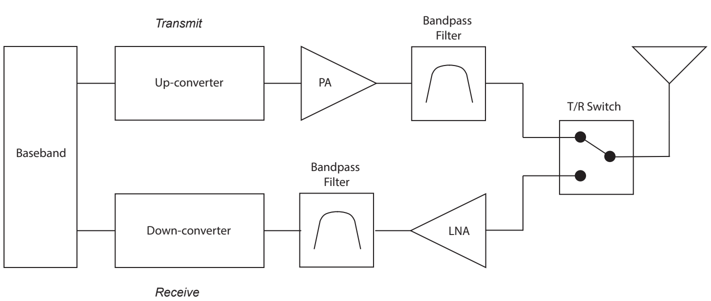

FIGURE 1. Simplified TDD Architecture

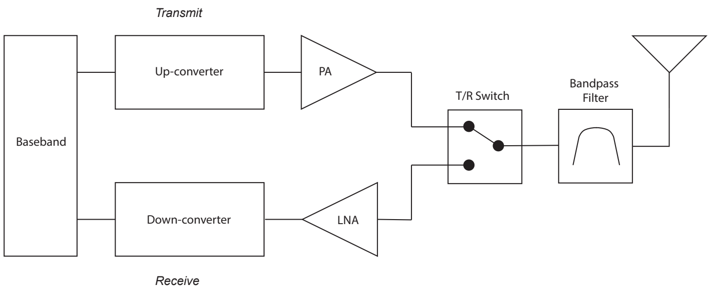

FIGURE 2. Alternative Simplified TDD Architecture

On the Receive side in figure 1 the signal at the output of the antenna is routed through the T/R switch to a low noise amplifier (LNA) that has enough gain to achieve the target noise figure. The LNA then drives a bandpass image filter, which is designed to remove received noise that has been amplified by the LNA. From there the RF signal passed through a down-conversion stage and into the baseband portion of the system for conversion into digital signals for processing.

On the transmit side of figure 1 the baseband signals drive an up-conversion stage, which in turn drives a power amplifier (PA) designed to reach the link budget goal. The PA drives a bandpass filter, which is designed to suppress broadband noise from the PA and out of band image and carrier feed through products.

Filters are necessary on both legs of the journey to suppress interference between different systems. Placing filters in the transmit path to improve out of band emission reduces adjacent channel interference to other systems from the transmitter. Placing filters in the receive path improves the receivers adjacent channel rejection of interference from other systems.

Where the filters are placed depends on the particulars of the system. Figure 1 shows filters placed in line with the gain stages, where figure 2 places them between the T/R switch and the antenna element.

MIMO and Beamforming

Earlier we mentioned MIMO (multiple-input and multiple-output) as an essential piece of 5G technology. MIMO refers to the technique of using more than one antenna to send and receive data. MIMO delivers an increase in channel capacity through Diversity Gains, in which multiple Transmitters and or multiple Receivers exchange the same data, increasing the overall signal to noise ratio (SNR) of the system, and Multiplexing Gains, in which data can be split across multiple Transmitters and Receivers and then re-combined on the receive side.

A related but distinct concept is that of Beamforming, which is adjusting the radiation pattern of an antenna array. The technique is well established in Phased Array radar systems where elements of an antenna array are arranged, and phase and amplitude of the signal at each element is controlled, in such a way that signals at particular angles undergo constructive interference while in other directions they experience destructive interference. This allows a transmitter to 'point' signals in a given direction and also for a receiver to 'listen' in a given direction also.

Radio systems that utilize beam forming essentially take multiple copies of the simplified block diagrams in figures 1 and 2 and multiply them across an antenna array, with the addition of the ability to adjust the phase and amplitude of the transmit and receive paths. How the phase and amplitude shift is implemented and where (is it done in the digital domain, or in the RF, or some combination of both) is the subject of some debate. But in general there seems to be a trend, for mmWave systems at least, towards Hybrid Beamforming, where the work of adjusting individual channels is split between the digital and analog domains.

Hybrid Beamforming

In hybrid beamforming a combination of digital and analog beamforming is used. N digital paths is split into M RF paths, driving a total of N x M antenna elements. This architecture combines multiple antenna array elements together into a subarray panel. The number of elements in each subarray is selected to ensure that the performance is met while minimizing the complexity of the design.

In figure 3 some elements from figure 2 are replicated in the front ends and a beamforming stage is added between the front ends and up/down conversion blocks.

The antenna array is split up into subarrays, and each subarray is fed by a set of front ends and beamformers. In this example the design is aiming for one baseband path for every 16 active antenna elements, although this ratio varies depending on the intended application for the beamforming array. We start with a total

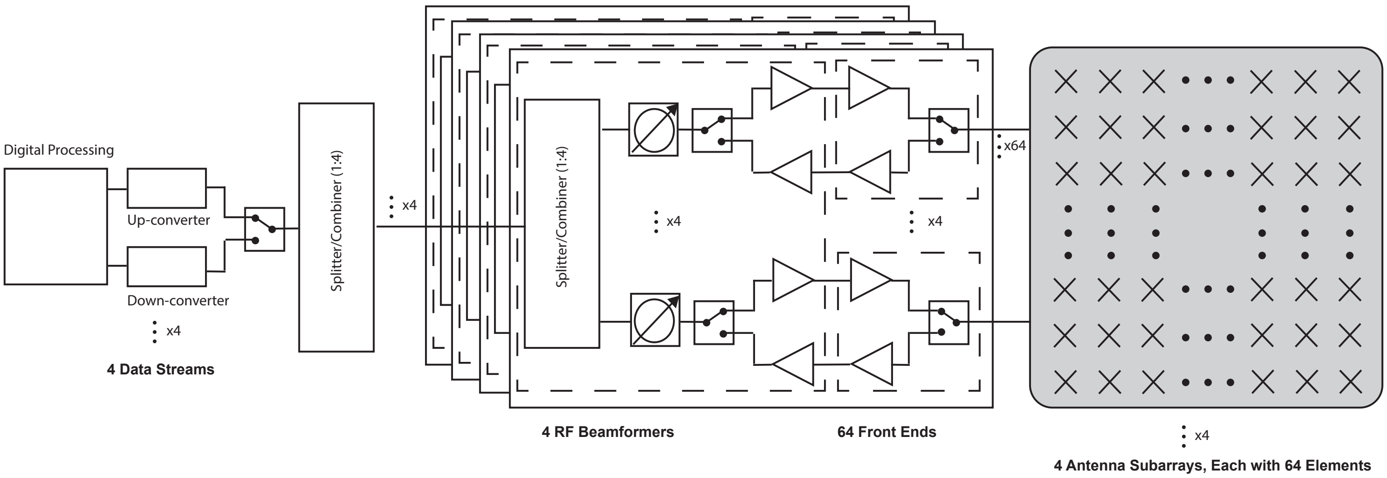

FIGURE 3. Simplified Hybrid Beamforming Architecture

of 4 baseband paths. Each baseband path drives 4 beamformers. Each beamformer splits the RF signal 4 ways to drive 4 front end modules, (FEM) and each FEM feeds an antenna element inside a subarray. This gives us 64 FEMs per subarray. There are 4 subarrays so we have a total of 256 antennas. The panels are dual polarized to the entire array consists of 512 active elements.

It should be noted that in figure 3 we have left out the necessary RF bandpass filters. These are likely to be implemented close to the gain stages, so possibly between each FEM and its associated antenna element, and/or between the beamformer and the FEM it is driving, but they may also be necessary between the first splitter/combiner and the up/down conversion blocks. Location of the RF bandpass filters depends on the interference constraints that a particular design is facing.

SMD for Beamforming Architectures

To produce such systems in a standard assembly processes such as SMD lead free pick and place manufacturing hinges on the availability of key building blocks in surface mount packaging. Looking at the key components of our example architecture (and including the filters that we know will be necessary) we arrive at the list in Table 1.

One solution for ease of manufacture would be to have all of these blocks available in one on chip solution. This would not be practical however for several reasons, including the need by designers to adjust a the architecture to suit the application, the dominance of different semiconductor technologies in different blocks and the likely need for the filtering components to be implemented off-chip, since on chip solutions cannot deliver the necessary performance in real world applications.

Usually a subset of these components are available as in integrated modules. So for example mmWave surface

TABLE 1. KEY COMPONENTS IN THE HYBRID BEAMFORMING ARCHITECTURE AND THEIR AVAILABILITY IN SMT PACKAGES.

Key Component	Available at mmWave frequencies?	Available in SMT packages?
ADC/DAC	*na*	*YES*
UP/Down Converters and or Modulator/Demodulators	*YES*	*YES*
Splitter/Combiners	*YES*	*YES*
Phase Shifters	*YES*	*YES*
LNA	*YES*	*YES*
Power Amplifier	*YES*	*YES*
Filters	*YES*	*YES*
Switches	*YES*	*YES*
Antennas	*YES*	*YES*

mount modulator/demodulators, RF beamformers and RF front ends are available on the market today. And where components need to be stand alone, mmWave SMD packaged devices can be sourced.

At Knowles Precision Devices our high performance Dielectric Laboratories (DLI) brand microstrip filters are provided with metallization schemes compatible for both chip and wire filters, and solder-surface mount filters. For ease of manufacturing we would recommend using the SMD approach but can support hybrid if that is your requirement.

Exceptional performance demands rigorous engineering, both of the component and of its interaction with the system. The design of a surface mount filter's shielding is a crucial element for achieving laboratory-grade performance outside of the laboratory and assuring smooth integration with the system. Shielding protects the filter from interference and creates a precisely controlled micro-environment for optimal performance. There are three packaging options available for RF shielding:

Printed wire board (PWB) covers are one solution offered by Knowles Precision Devices within the Dielectric Laboratories (DLI) brand. This style of cover offers excellent RF shielding for solder surface mount applications. Additionally, PWB covered components are extremely resistant to high shock and vibration environments. These covers attached using epoxy; the cured assemblies offer a small and sturdy surface mount package that can integrate multiple filters in one pc. The overall height of the package is typically 0.1 inch (2.54mm). However above 10GHz discuss with our engineering team - performance at higher frequencies may be limited.

A second option for shielding is the attachment of an integral metal cover to the filter. Sheet metal covers are compatible with both solder surface mount and chip and wire filter applications. Typically, this style cover is grounded/attached along the perimeter of the part, creating a strong bond and improving overall filter isolation. Covers can be recessed to expose the I/O contact pad for chip and wire filters to allow wire-bonding. The overall assembly height can vary from 0.070 to 0.10 inch (1.78 to 2.54mm).

The third option leaves packaging up to the customer. Either the next level of assembly provides the RF shielding for the filter or the customer can have their own cover integrated.

The Knowles Precision Devices DLI engineering team can provide recommendations for housing dimensions, leveraging years of expertise to ensure successful design integration. If the customer provides their own shielding for the filter, it is very important that our engineering team knows the channel width and cover height that will enclose the device. These dimensions will be taken into account during design and test to ensure that the part will work in its next level of assembly. Where the customer is assembling their own cover, the tolerance of placement of this shield can affect overall filtering performance and should be considered.

Knowles Precision Devices (DLI brand), provides high performance surface mount solderable filters in a reduced footprint compared to filters implemented on substrates like Alumina and with precision engineered package shielding that ensures the devices continue to perform as specified once integrated into a system. Filter packaging is compatible with many conformal coating processes as well for robust board assembly.

As mentioned earlier in the article a components price is only one part of a designs overall cost, since the ability to bring a design into the world in a cost effective manner hinges on the availability of standard manufacturing processes.

Mixing technologies, as in the Hybrid approach where chip and wire and surface mount techniques are combined, necessitates an increase in manufacturing complexity that can be a cost driver.

Where the key active components in systems such as the ones described in this article can be sourced either as surface mount packaged components or as stand-alone SMD devices, taking a close look at the packaging technology available to implement high performance filters in a design can save considerable cost and complexity when it comes to manufacturing a new design. The performance repeatability inherent in both the filter technology itself and the way in which the manfacturing approach impacts the overall circuit repeatability are both keys to this reduction in complexity and cost.