From August 2011 *High Frequency Electronics*

Design Requirements for Integrated Microwave Avionics Receivers

By Leo G. Maloratsky
Aerospace Electronics, Co.

This article discusses various approaches to solving design problems in RF and microwave avionics receivers, with recommendations for design strategy of the optimal receiver

The acronym *avionics* is a combination of *AVI*ation and electr*ONICS*. The general direction of a modern electronics is integration or size reduction. With recent reductions in the size of physical circuits, we may also require an abbreviation of electronics acronyms. Therefore, the mainstream of aviation systems with microwave integrated circuits can be named by the acronym *avmic*, formed from letters of words *AV*iation *M*icrowave *I*ntegrated *C*ircuits. The author used the more common acronym *avionics* in the title of the article to be better understood by the readers. The changing of terminology (if necessary) is a decision for the experts in the future.

Avionics has come to include communications, navigation, flight control, collision avoidance, military applications, landing aids, guidance and lighting, as well as electronics systems involved with the display and management of multiple systems [1-6]. Avionics refers to electronic systems on aircraft, artificial satellites and spacecraft that provide communications, navigation and guidance, display systems, flight management systems, sensors and indicators, weather radars, electrical systems, and various computers onboard modern aircraft and spacecraft. It includes hundreds of systems fitted to aircraft to meet individual roles.

The avionics industry is now a major multibillion dollar industry and accounts for around 30% of the total cost of the aircraft. Integration of avionics systems is a significant issue because the reduction in weight can be translated into longer range on less fuel and/or more passengers. Also, other very important issues are cost reduction, increased safety, improved aircraft performance, and size reduction.

Avionics Receiver Requirements

These are the following specific requirements for the avionics RF and microwave receiver (RX):

- Narrow frequency band (from 0.2% for the Transponder up to 6% for the TCAS) or moderate frequency band (23% for the DME);
- Large dynamic range (up to 90 dB for the Weather Radar);
- Small or moderate manufacture quantity (from several hundred samples to tens of thousands samples per year);
- Strong resistance to environmental conditions (temperature, vibration, humidity, etc.);
- Very low size and weight;
- Low cost

For avionics microwave RXs, high integration, low cost as well as power and mass efficiency are particularly important. The development of new avionics RX is driven by the needs of all areas of space applications. The key drivers can be summarized as follows:

- Higher dynamic range, more resolution, more channels.
- Low power consumption: spacecraft operate in an environment where the availability of electrical power is very limited,

and the cost of power in terms of spacecraft mass is very high.

- Low mass: miniaturization of RX is often an enabling factor for demanding avionics systems, where miniaturization often goes hand in hand with a reduction of power consumption, which allows achieving further mass savings.
- Low RX cost: an important factor for reducing avionics systems cost; the reduction of mass and power consumption allows significant overall cost savings.

Microwave typically refers to radio frequencies from 1 to 300 GHz. Microwave avionics systems include Microwave Landing System (MLS), Radio Altimeter (RALT), Global Positioning System (GPS), TCAS, XPDR, DME, Automatic Dependent Surveillance-Broadcast (ADS-B), Universal Access Transceiver (UAT), Traffic Information Services (TIS-B), Flight Information Services—Broadcast (FIS-B), Joint Tactical Information Distribution System/Multi-functional Information Distribution System (JTIDS/MIDS), WXR.

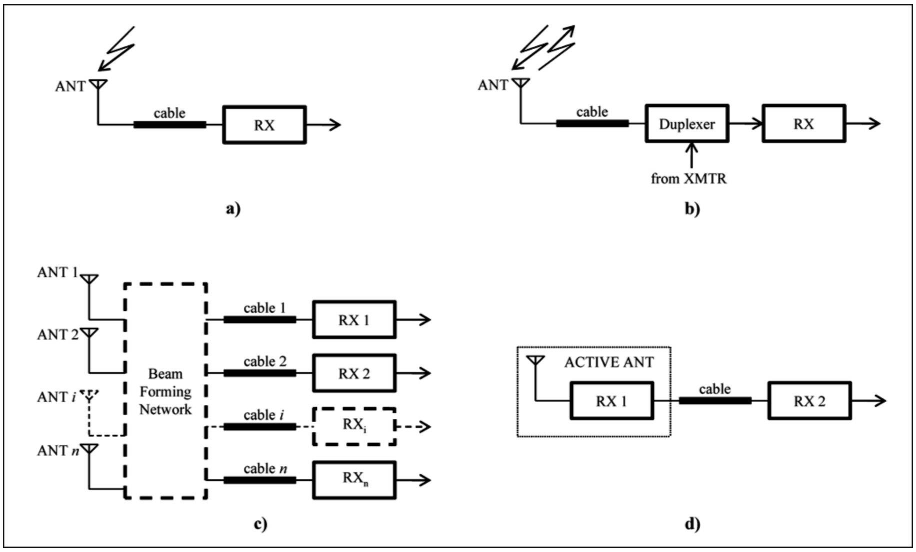


Figure 1 · Basic receiver architectures used in avionics RXs.

				Avionics Systems					
Performance	TCAS	XPDR Mode S	DME	UAT	GPS L1 L5 L2	RALT	MLS	ADS-B	WXR
FR (MHz)	1090.0 +/- 3.0	1030.0 +/- 0.1	962.0 - 1213.0	978.0 +/- 1.0	1575.42 1176.45 1227.60	4200.0 - 4400.0	5031.0 - 5090.7	1090.0 +/- 1.0	9375.0
Sensitivity (dBm)	-72.0 (A0); -79.0 (A1,A2) -84.0 (A3)	-77.0	-85.0	-93.0	-127.0 -125.0 -127.0	-93.0	-106.0	-84.0	-120.0
DR (dB)	68.0	56.0	73.0	80.0	20.0 56.0	70.0	86.0	63.0	90.0
BW (MHz)	6.0	0.2	251.0	2.0	24.0 20.46 24.0	200.0	60.0	2.0	60.0

Table 1 · Microwave receiver performance of different avionics systems.

The principal functions within microwave RXs are: filtering, amplification, frequency down conversion, isolation (ISO) between transmitter (XMTR) and RX (if necessary), protection from parasitic signals, channel switching (if necessary), and self-test. The RXs of avionics systems are connected to antenna (ANT) through cables. These networks have a different architecture, which is represented in Figure 1. All microwave RXs can be implemented in the two following architectures: without XMTR (or separated from XMTR) and combined RX/XMTR or transceiver (XCVR) with common antenna system. The XCVR (Fig. 1b) requires the special duplexer for separation of a RX from a XMTR. The multichannel RX (Fig. 1c) is used in systems with antenna array, multi-antenna systems, etc. In the modern high sensitivity systems, the active ANT (Fig. 1d) can be used.

The main characteristics of the microwave RX depend on aircraft system requirements. The system specification should be transform into microwave receiver requirements. Table 1 shows the specifications of the microwave avionics RXs.

Receiver Components

Microwave RXs are based on the use of:

- Planar transmission lines;
- Distributed and lumped passive components;
- Passive devices;
- Control devices;
- Active solid-state devices;
- Passive and active antennas.

More than 30 different types of planar transmission lines have been developed over the past four decades, often in guest of additional BW, lower insertion loss (IL), smaller size, or other performance advantages. There are several reasons for the wide use of planar transmission lines in microwave RX [7-12]. First of all they are broadband while providing compact dimensions and light weight. Foremost, they are generally economical to produce as they are readily adaptable to hybrid and monolithic integrated circuit fabrication technologies at RF and microwave frequencies. Each planar transmission line offers certain advantageous features with respect to other types (see Table 2).

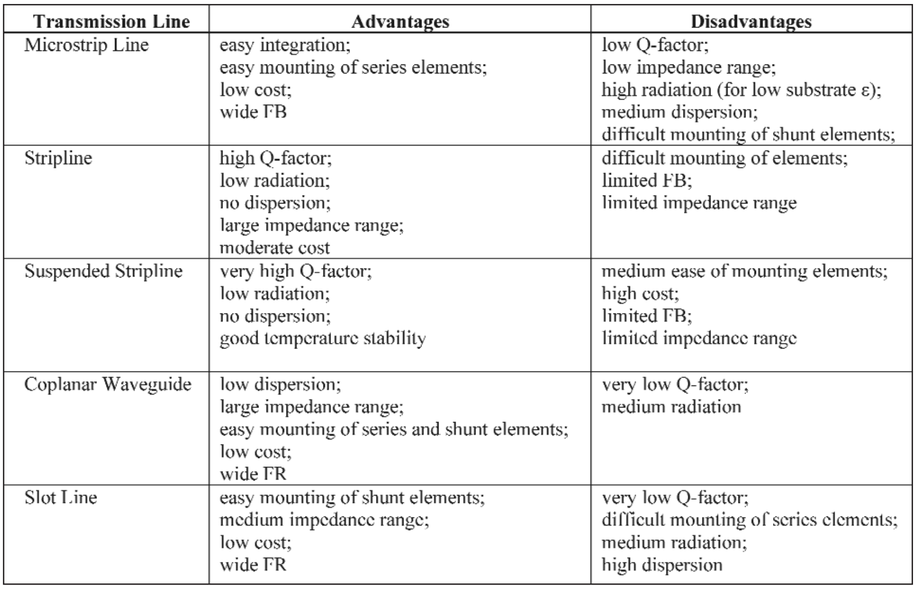
All planar transmission lines

have strip conductor(s) implemented on a relatively thin substrate. Typical substrate materials are slabs of dielectric, ferrite, or high-resistivity semiconductor. In most cases, there are metal ground planes that can either be printed on the same substrate or be a part of the metal housing. Planar transmission lines can be classified as being uniform or nonuniform; homogeneous or inhomogeneous in their surrounding area; lossless or lossy; shielded or non-shielded; planar, multilayer, or three-dimensional. They are also based on different substrate types, including dielectric, ferrite, or semi-insulating materials. In a uniform line, the characteristic impedance does not vary with position along the line. A nonuniform printed transmission line exhibits characteristic impedance that varies as a function of the position along the line. Usually, this change in impedance is achieved by changing the conductor strip width. Tapered transmission lines can be fabricated with smooth changes in conductor width and characteristic impedance as functions of distance along the line.

Passive RF and microwave integrated circuits comprise distributed elements, lumped elements, or combinations of both these types of elements. Distributed elements consist of segments of transmission lines of the different types we have discussed in the preceding chapters. These transmission-line segments can be of various lengths ranging from small fractions of a wavelength (λ) to several wavelengths. A planar lumped element refers to single-layer circuit that consists of different configurations of conductors printed on substrates.

Lumped elements are small in size with linear dimensions that are usually less than λ/10 or λ/16 (λ is guide wavelength). At this size, transmission line effects do not play a significant role in their function. There are no appreciable variations in phase over the lumped element, and the current distributions and associated potential drops are essentially uniform. Lumped elements have the advantages of small size, low cost, wide-band performance, large impedance transformations, minimum interactions between elements, but have low *Q*-factor and power handling capability than distributed elements. Lumped elements are especially suitable for monolithic integrated circuits, where size requirements are of most important. Lumped elements are usually easily realized in RF or low-frequency microwave applications. At higher microwave frequencies, and particularly at millimeter-wave frequencies, lumped elements are very difficult, or even impossible, to achieve because of dimensional limitations in fabrication technologies and parasitic [5]. A lumped element has parasitics because of the not insignificant physical dimensions. The effects of the parasitic capacitance and inductance increase as the operating frequency increasing. Lumped elements are not purely inductive, resistive, or capacitive, but have aspects of all three due to undesirable parasitic. Because of these parasitic effects, lumped elements will resonate at some frequency. The upper limit for the use of lumped elements is approximately 30 GHz.

Lumped elements have been used to realize many circuit functions, such as matching networks, filters, transformers, dividers/combiners, directional couplers, baluns, phase shifters, switches, bias chokes, high-power oscillators, LNA, power amplifiers, etc. Planar lumped elements are used in hybrid microwave integrated circuits (HMICs) and monolithic microwave integrated circuits (MMICs). In applications where it is possible to utilize lumped elements, the advantages are usually small dimensions, wideband characteristics, and low production cost. Lumped-element circuits exhibit a lower quality factor Q than distributed circuits. The lumped elements can be reactive or lossless, resistive or lossy or combination of both. "An Achilles' heel" of lumped-element circuits, low *Q*-factor, limits application of these circuits, but this situation can be improved by combinations of lumped elements with distributed elements, discrete elements, ground plane modification, etc. Planar lumped element *Q*-factor depends on the following factors: parasitics,



Transmission Line	Advantages	Disadvantages
Microstrip Line	easy integration; easy mounting of series elements; low cost; wide FB	low Q-factor; low impedance range; high radiation (for low substrate ε); medium dispersion; difficult mounting of shunt elements;
Stripline	high Q-factor; low radiation; no dispersion; large impedance range; moderate cost	difficult mounting of elements; limited FB; limited impedance range
Suspended Stripline	very high Q-factor; low radiation; no dispersion; good temperature stability	medium ease of mounting elements; high cost; limited FB; limited impedance range
Coplanar Waveguide	low dispersion; large impedance range; easy mounting of series and shunt elements; low cost; wide FR	very low Q-factor; medium radiation
Slot Line	easy mounting of shunt elements; medium impedance range; low cost; wide FR	very low Q-factor; difficult mounting of series elements; medium radiation; high dispersion

Table 2 · Comparison of various planar transmission lines.

physical dimensions, transmission line, dielectric performance, conductor performance (loss, structure, configuration, resistance, and dimensions), and ground plane structure. Table 3 illustrates performances of planar lumped elements and distributed elements.

Basic passive components that are used in modern avionics microwave receivers are directional couplers, power dividers/combiners, filters, baluns, ferrite isolators and circulators. Passive components are prevalent in microwave front-ends. For example, it is estimated that in an avionics front-end (see Table 4), passive components account for 63% of the component account, 71% of the size, and 70% of the cost. In a single-mode wireless phone, passive components account for 90% of the component count, 80% of the size, and 70% of the cost.

Performances	Lumped Elements	Distributed Elements
Maximum *Q*	10 - 200	500
Maximum Capacitance (pF)	1.0	
Maximum Inductance (nH)	10.0	
Size	very small	moderate
Cost	very low	moderate
BW	wide (including VHF, UHF bands)	moderate
Maximum Frequency	30 GHz	millimeter wave frequencies
Power Handling Capability	low or moderate	high
Parasitic Coupling Effect	small	moderate
Large Impedance Transformation Ratio	high (up to 20:1)	moderate

Table 3 · Performance comparisons of planar lumped elements and distributed elements.

	Passive Components					% of Receiver		
Avionics Front-End	Directional Coupler	Divider/ Combiner	Filter	Balun	Ferrite Isolator/ Circulator	Component Account	Size	Cost
DME	1		1	1	1	71	80	70
XPDR	1		4	1		60	70	80
TCAS		8	16	8		60	65	70
MLS	1		4	1		50	60	40
RADALT	1		2		1	70	83	85
TCAS/XPDR	8	8	24	8		70	70	80

Table 4 · Passive components number in avionics front-ends.

Avionic System	Switch Type	Switch Function
DME	SPDT SPST SPST	Duplexer Switching of LO power Switching of noise source
XPDR	SPDT SPDT	Switching of top and bottom ANTs T/R switching
TCAS	SPDT SPDT	Switching of top and bottom ANTs Duplexer
MLS	SP3T	Switching of landing, the tail, and the omni ANTs
RALT (single ANT)	SPST	Switching of LO power
ADS-B	SPDT	T/R switching
TCAS/XPDR	SPDT SPDT SPST	Switching of top and bottom ANTs Duplexer Switching of phase shifter lines in antenna array

Table 5 · Applications of switches in avionics RXs.

System Functional Blocks

1. Control Devices

Control devices for avionics microwave receivers are switches, limiter circuits, phase shifters. The microwave switches are widely used in avionics receivers (see Table 5). Limiters are primarily used in RXs to protect power sensitive components and devices (e.g., LNA, mixer) from nearby high power sources. In avionics RXs, these signals may arise from XMTR and outside parasitic strong signals. The author has experience with failures of the weather radar, which was damaged by the weather radar of another aircraft on the runway. This defect was eliminated by the optimization of the limiter circuit in the weather radar RX.

RF and microwave phase shifters have many applications in various equipment such as phase discriminators, BFNs, power dividers, balanced amplifiers, and phase array antennas. A phased array antenna has a large number of radiating elements that emit phased signals to form a radio beam. The radio signal can be electronically steered by the active manipulation of relative phasing of individual antenna elements. Phase shifters are fundamental part of any phased array antennas. They allow an array to scan a beam or reconfigure a shaped beam. Phased antenna arrays, such as the avionics TCAS ANT, consist of a number of individual elements, each one requiring a phase shifter that applies the necessary phase shift to steer the antenna beam. In some avionics amplitude monopulse systems, a phase shifter provides different directional and omnidirectional antenna modes [13, 14].

2. Duplexers

The transceiver duplexer is a key element in avionics systems, radars, antenna arrays and wireless communication systems. The duplexer provides protection of the front-end and transmitter from unwanted parasitic signals [15]. A microwave transceiver duplexer connecting a single ANT to the XCVR is often the key component in phase array, radar, communications and navigation systems. A duplexer directs transmitter energy to a single antenna during the transmit mode and the energy received by the antenna to the receiver during the receive mode. The duplexers should meet the following objectives:

- Reduce the number of antennas (a single antenna is used for transmitting and receiving)
- Reduce the number of cables connecting the transceiver with the single antenna
- Reduce the potential transmitter pulling, intermodulation and noise due to antenna mismatch
- Protect the RX from unwanted (parasitic) synchronous and non-synchronous signals
- Reduce cost, maintenance and mechanical complexity

3. Diplexers

A diplexer is a three-port passive device that implements frequency domain multiplexing. Do not confuse the word *diplexer* with *duplexer,* which is the three-port network that permits a transmitter and receiver to use the same antenna, at essentially the same frequency band. A diplexer multiplexes two ports onto one port, but more than two ports may be multiplexed. A typical diplexer consists of two fixed tuned BPFs that share a common port. The common port and two outputs of the two filters form the three terminals of the diplexer. Signals applied to the common port are separated in accordance with the pass band frequencies of the BPFs. To design a multiplexer, component filters should be connected in such a way that each filter appears as an open circuit to each other filter. For the design of diplexers only one open circuit condition should be satisfied and this can be done using optimization of the T- or Y-junction. It has been found that using the Y-junction introduces fewer losses than the T-junction. In integrated avionics RX multiplexers are used to split wide BW signals of several avionics systems from common ANT into different paths for each system. In an airplane many different systems may be used simultaneously. Compact equipments that support multi-mode/multi-band front-end are very attractive and will be widely used in the future. The front-end multiplexer consists of several BPFs in n channels sharing a common path. Received signals from common ANT are separated in accordance with the passbands of the BPFs. Thus, signals in different front-end channels are isolated from the each other.

4. Low Noise Amplifiers (LNA)

A LNA is a key component in the microwave RX. The LNA at the microwave RX sets the system noise figure (NF) or sensitivity. The LNA should provide enough gain to overcome any noise added by components following it, such as the mixer, BPF.

The NF of first amplifying stage of LNA has a predominant effect, while the NF of the subsequent stages is of lesser importance. The desirable electrical characteristics of an LNA are gain (G), NF, isolation (ISO), return loss (RL), dynamic range (DR), band width (BW) and power consumption. Setting high G to the LNA will help reduce the NF by minimizing the noise contribution of the mixer and reduce the emission of spurious CW RF energy, but at the expense of higher power consumption in the blocks and the risk of early mixer overloading. For lower LNA gain, a very low noise mixer would be required to maintain an acceptable NF. The G of the LNA should be the result of a compromise between the following contradictory characteristics: maximum RX sensitivity, maximum possible mixer input RF power, and minimum LO leakage at the antenna port. The amplifier tuned for the best NF will not have the optimal input RL. In the RX with the circulator duplexer, the LNA reflection signal does not reach the antenna input because the circulator isolates the LNA from the antenna input during the receive mode. However, the RL should be minimized in order to provide a low mismatch loss, which influences the RX sensitivity. High reverse ISO of a LNA is important to attenuate local oscillator energy from a mixer to ANT. The LNAs G and NF compromise is a classical trade-off. The G of the LNA should be a result of the compromise between the following contradictory characteristics: RX sensitivity, maximum possible mixer input RF power, and maximum LO-RF leakage at the antenna port. Setting high G to the LNA the expense of higher power consumption in the blocks after the LNA and risk of early mixer overloading. Too much power into the mixer will cause compression, while not enough power will shrink the potential DR. Unfortunately, the LNA creates broadband noise (hopefully very small) which will appear at the image frequency have its noise power directly converted into the IF band. This has the effect of reducing the overall receive sensitivity.

5. Mixers

A very important device in avionics RX is the microwave mixer. A mixer is a nonlinear device that converts an RF signal to an intermediate frequency (IF) by combining the RF signal with a higher power signal of local oscillator (LO). This device must satisfy all required LO and RF input frequencies as well as all IF output frequencies. In the event of a large LO signal pickup, the total NF will be degraded. The level of LO signal picked up at the antenna input must be kept below –70 dBm. The following guidelines should minimize LO pickup at the RX:

1. Use RF mixer with high LO-RF ISO.
2. Use LNA with maximum G.
3. Position the LO circuitry away from the LNA circuitry.
4. Use a grounded screen to cover all of the LO components.

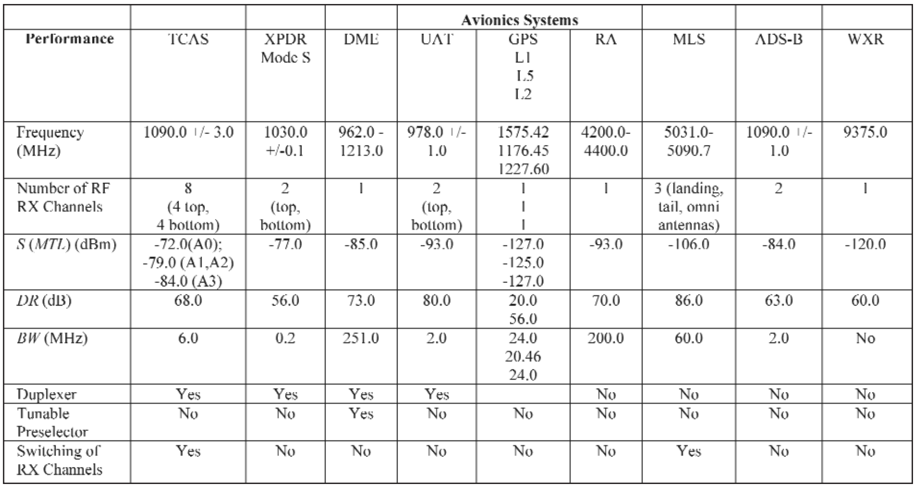
The choice of the mixer IF is very important and will result in many trade-offs. A low IF allows great suppression of adjacent channel interferences, while a high IF gives substantial image rejection and high DR. In the double-converting superheterodyne RX, high first IF gives good image rejection and low second IF gives good selectivity. The mixer compression level is the maximum power level that we can put into RX output without compromising the accuracy of the output signal. As the signal level increases, the mixer transfer function becomes nonlinear because significant energy is lost to the distortion product.

System Factors

The basic super-heterodyne architectures of avionics RXs consist of several key components:

- Matching circuits to allow all the received energy from the ANT to get to the next stage
- BPF and/or LPF to knock down out-of-band jammers
- LNA—its primary responsibility is to set the receive sensitivity of the RX, by offering high gain and very low NF
- RF mixer for down converting from RF to IF
- Duplexer for connection of a single antenna to a RX and XMTR (if necessary)
- Diplexer for signal separation in the combined multichannel RXs

The conventional antenna modules are passive device, where the RX connected after the lossy cable has low sensitivity and therefore an aircraft range measurement is limited. The position of the first LNA in the RX limits the minimum NF (maximum sensitivity) due to IL of the circuit before the LNA. For example, according to [1], the existing avionics cable has a maximum loss of 3 dB. Also, the cable matching might be up to VSWR = 1.7 that lowers the electrical performance of the antenna module. The components of the microwave module are typically designed using analog circuits. As it is extremely difficult to design microwave components over a broad range of avionics system frequency bands, each microwave RX is typically designed for a certain band of frequencies and the band width of the channels. Table 6 shows characteristics of microwave front-ends of different avionics systems.

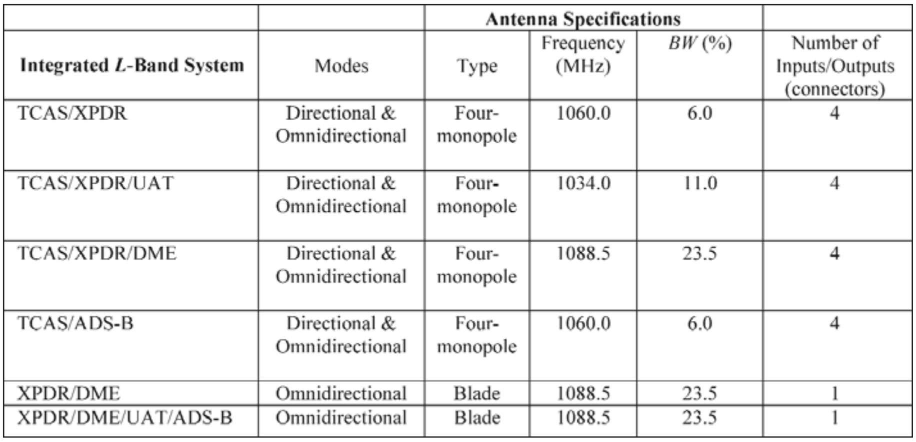


				Avionics Systems					
Performance	TCAS	XPDR Mode S	DME	UAT	GPS L1 L5 L2	RA	MLS	ADS-B	WXR
Frequency (MHz)	1090.0 +/- 3.0	1030.0 +/-0.1	962.0 - 1213.0	978.0 +/- 1.0	1575.42 1176.45 1227.60	4200.0-4400.0	5031.0-5090.7	1090.0 +/- 1.0	9375.0
Number of RF RX Channels	8 (4 top, 4 bottom)	2 (top, bottom)	1	2 (top, bottom)	1 1 1	1	3 (landing, tail, omni antennas)	2	1
S (*MTL*) (dBm)	-72.0(A0); -79.0 (A1,A2) -84.0 (A3)	-77.0	-85.0	-93.0	-127.0 -125.0 -127.0	-93.0	-106.0	-84.0	-120.0
DR (dB)	68.0	56.0	73.0	80.0	20.0 56.0	70.0	86.0	63.0	60.0
BW (MHz)	6.0	0.2	251.0	2.0	24.0 20.46 24.0	200.0	60.0	2.0	No
Duplexer	Yes	Yes	Yes	Yes		No	No	No	No
Tunable Preselector	No	No	Yes	No	No	No	No	No	No
Switching of RX Channels	Yes	No	No	No	No	No	Yes	No	No

Table 6 · Microwave RX performance of different avionics systems.

The last decade has been marked by rapid developments in integrated avionics systems. The autonomic systems are heavy, occupy a substantial amount of space and are very costly. The advantages of the integrated systems include fewer units, smaller size, less weight, lower power use, reduced cable count, extensive built-in test equipment (BITE) and integrated features. Integrated microwave RX of the avionics systems has common antenna module, common XMTR and single multichannel RX. For microwave integrated avionics systems, cost is the dominant factor. The combined microwave systems require a multi-channel RX, which makes allowance for, one hand, in a large number of receiving channels each with a large DR, and, on the other hand, low cost, small volume, low weight, and low dissipation of these RX channels.

The passive and active antenna modules are very important components of avionics microwave RX. The avionics systems with the TCAS, the RX includes an antenna module with a beam forming network. For the active antennas, the RX includes an antenna module with the first LNA and T/R network. A conventional TCAS antenna array is passive system. A TCAS XMTR with pulse power of about 200 W provides a transmit range of 45 nautical miles given the typical directional antenna *G*. During receive operation, signals received by the antenna elements are conveyed at very low power levels, because there is no power boosting from the passive antenna array. Receiver sys-



		Antenna Specifications			
Integrated *L*-Band System	Modes	Type	Frequency (MHz)	*BW* (%)	Number of Inputs/Outputs (connectors)
TCAS/XPDR	Directional & Omnidirectional	Four-monopole	1060.0	6.0	4
TCAS/XPDR/UAT	Directional & Omnidirectional	Four-monopole	1034.0	11.0	4
TCAS/XPDR/DME	Directional & Omnidirectional	Four-monopole	1088.5	23.5	4
TCAS/ADS-B	Directional & Omnidirectional	Four-monopole	1060.0	6.0	4
XPDR/DME	Omnidirectional	Blade	1088.5	23.5	1
XPDR/DME/UAT/ADS-B	Omnidirectional	Blade	1088.5	23.5	1

Table 7 · Antenna module specifications.

tems incorporating passive antenna arrays have an inherent receive range that is dependent, among other things, upon the characteristics of the passive components provided along the receiver path, as well as noise, loss, sensitivity and other factors. The limited receive sensitivity is due in part to cable losses and noise within the receive signal path. In certain applications, it is desirable to provide a TCAS receive range of 100 nautical miles, which may not be possible with conventional passive antenna systems. This disadvantage can be eliminated by using the active antenna.

Table 7 illustrates antenna module specifications for different integrated avionics L-band systems. The ANTs of the integrated systems, including TCAS, can be operated in two configurations. The top antenna module must provide the directional and the omnidirectional modes. Separate omnidirectional antennas are not required for the added functionality. The bottom antenna module may be either likewise directional/omnidirectional or sometimes omnidirectional only to reduce cost. In integrated systems without TCAS (XPDR/DME; XPDR/DME/UAT/ADS-B), the typical antenna is a vertically polarized metal blade with one BNC or TNC connector. Most of the L-band blade antennas are thin blades about a quarter wavelength in height due to aerodynamic considerations.

References

1. R. P. G. Collinson, *Introduction to Avionics Systems,* Second Edition, Kluwer Academic Publishers, 2003.

2. M. Golio, Editor, *Microwave and RF Product Applications,* CRC Press, 2003.

3. L. G. Maloratsky, "RF Design of Avionics L-band Integrated Systems," *Microwave Journal,* Vol.52, No.10, Oct. 2009, pp.64-82.

4. A. Helfrick, *Principles of Avionics,* Avionics Communication, 2007.

5. M. Golio, J. Golio, *RF And Microwave Applications and Systems,* CRC Press, 2007: Chapter 13, J. L. Bartlett, "Microwave and RF Avionics Applications."

6. (same as Ref. 1)

7. H. Howe, Jr. *Stripline Circuit Design,* Artech House, Norwood, MA, 1974.

8. S. K. Koul, B. Bhat, "Broadside-Edge Coupled Symmetric Strip Transmission Lines," *IEEE Trans . Microwave Theory Tech.,* Vol. MTT-30, 1982, pp.1874-1880.

9. T. C. Edwards, *Foundations for Microstrip Circuit Design,* John Wiley & Sons, 1981.

10. C. B.Wadell, *Transmission Line Design,* Handbook, Artech House, Norwood, MA, 1991.

11. L. G. Maloratsly, "Setting Strategy for Transmission Lines," *Microwaves & RF,* Part 1, Sep. 2008, pp.100-112, Part 2, Oct. 2008, pp.84-86.

12. L. G. Maloratsky, *Passive RF and Microwave Integrated Circuits,* Elsevier, 2004.

13. B. E. Dinsmore, D. M. Smith, "Apparatus and Method for an Amplitude Monopulse Directional Antenna," U.S. Patent No. 5,191,349, Mar. 2, 1993.

14. L. G. Maloratsky, "Switched Directional/Omnidirectional Antenna Module for Amplitude Monopulse Systems," *IEEE Antenna and Propagation Magazine,* October 2009.

15. L. G. Maloratsky, "Transceiver Duplexer Design Consideration," *Microwave Journal,* Oct. 2008, pp.68-86.

Author Information

Leo G. Maloratsky received his MSEE from the Moscow Aviation Institute and his PhD from the Moscow Institute of Communications in 1962 and 1967, respectively. Beginning in 1962, he was involved in the research, development and production of RF and microwave integrated circuits at the Electrotechnical Institute, and he was assistant professor at the Moscow Institute of Radioelectronics. Later, he worked as a staff engineer at Allied Signal and a principal engineer at Rockwell Collins. In 2008 he joined Aerospace Electronics Co. He is author of four monographs, one textbook, over 50 articles and 20 patents. His most recent book is *Passive RF & Microwave Integrated Circuits*, Elsevier, 2004. Dr. Maloratsky can be reached at: lmaloratsky@cfl.rr.com