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Introduction to Basic RF for the Non-Engineer

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What is RF?

- Electrical energy moves from place to place in one of two ways:
 - It either flows as current along a conductor (a bunch of electrons moving down a metal wire)
 - It travels in the air as invisible waves.
- In a typical wireless system, the electrical energy starts out as current flowing along a conductor, gets changed into waves traveling in the air, and then gets changed back into current flowing along a conductor again.

Boat anchor

Refers to bulky and heavy test equipment from and earlier epoch, most often bearing the name Hewlett Packard. Old spectrum analyzers and synthesizers are among the most effective boat anchors.

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What is RF?

- The electrical signal flows as current along a conductor into the Transmitter.
- Inside the Transmitter, a bunch of stuff happens and out comes essentially the same electrical signal—only this time it is traveling through the air.
- Now traveling at the speed of light, the airborne signal reaches the Receiver.
- Inside of the Receiver, some more stuff happens and out pops, you guessed it, the same electrical signal as current flowing along a conductor.

Bravo Sierra Military jargon for "BS".





- RF (Radio Frequency) Generally referring to any frequency at which the radiation of electromagnetic energy is possible typically above 50 MHz.
- Microwave this word is often synonymous with RF, but it is mostly used to describe a range of frequencies. Typically 1000MHz and above.
- Transmitter It turns electrical current into airborne waves.
- Receiver It turns airborne waves into electrical current.

Bonepile

A collection of production assemblies that failed acceptance test. Often used as a low-cost source of shippable hardware, around the 29th of the month. Sample dialogue: Hey Joe, get your butt out here and work the bonepile, we need to make the numbers this month or it's pink slip blizzard time!



- Inductance the opposite of capacitance, it is a property that opposes an instantaneous shift in current. Inductance has no effect at DC (an inductor passes direct current), but as frequency increases an ideal inductor starts to look like an open circuit.
- Lumped Element Those systems in which electrical properties like R, L, C are assumed to be located on a small space of the circuit and are applicable for high frequency application. In Lehman's terms, a passive device that has the shape of a Capacitor or Resistor.
- Distributed Element This system assumes that electrical properties R, L, C are distributed across the entire circuit. These systems are applicable to for low frequency application.

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- Microwave Capacitors Are used as tuning elements, or as components in simple or complex filter structures.
- Microwave Resistors Axial-leaded resistors, the ones with the colorcoded rings that you might be familiar with from misspent youth of busting stuff to "see how it works", are not going to work at microwave frequencies. This is because you have to consider that anything with dimensions longer than perhaps a sixteenth wavelength acts as distributed element. It is desirable for a resistor to behave like a lumped element in most microwave applications.

Hybrid circuits

This is applied to any microwave circuit that employs a hermetic housing, alumina thin-film networks, and chip-and wire construction. It's called a *hybrid* because it's a combination of discrete devices and printed circuit (or thin-film) technology, in a single unit.



- Passive Device contains no source that could add energy to your signal
- Power Divider—They couple a defined amount of the electromagnetic power in a transmission line to a port enabling the signal to be used in another circuit.
- Antenna An electrical device which converts electric currents into radio waves, and vice versa. It is usually used with a radio transmitter or radio receiver.
- Phased Array An antenna array is a group of multiple active antennas coupled to a common source or load to produce a directive radiation pattern. Usually, the spatial relationship of the individual antennas also contributes to the directivity of the antenna array.

Belt and suspenders When you design something with added safety margin!



- Transmission Line any pair of conductors used to move energy from point A to point B. The size is usually controlled and in a dielectric to create a controlled impedance.
- Frequency the number of occurrences of a repeating event per unit of time. (Radio Frequencies are oscillations in the range of 30 kHz to 300 GHz.) See chart on next page.
- Coaxial A transmission line in which one conductor completely surrounds the other, the two being coaxial and separated by a continuous dielectric such as air or PTFE.
- Impedance Resistance to alternating current. Most RF and microwave systems are designed to operate with a characteristic impedance of 50 ohms.

Daughter board

A printed circuit board that is added to a larger printed circuit board, often the result of modifications during breadboard phase.



Why 50 Ohms?

The standardization of fifty ohm impedance goes back to developing coax cables for kilowatt radio transmitters in the 1930s. The quick answer is that 50 ohms is a great compromise between power handling and low loss, for air-dielectric coax.

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Prefix	Meaning	Example	Interpretation
(m) milli	1/1000	1mA	.001 Amps
(k) kilo	1000	5kg	5000 grams
(M) Mega	1 million	2MHz	2 million Hertz
(G) Giga	1 billion	100Gbucks	Bill Gates net worth

Chicken dots

Artwork features that don't affect the design, but facilitate tuning later. Gold chicken dots give you something to stick ribbon bonds to. This design practice dates back to when CAD tools were inaccurate, today you are better off spending the time to accurately predict design performance, and minimize the use of chicken dots. If you overdue it they can actually couple to transmission lines, pulling impedances out of whack and cause more harm than good.

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Frequencies



Frequencies

Band name	Abbr	ITU band	and wavelength in air	Example uses	
sub-hertz	subHz	0	< 3 Hz > 100,000 km	Natural and man-made electromagnetic waves (millihertz, microhertz, nanohertz) from earth, ionosphere, sun, planets, etc ^[citation needed]	
Extremely low frequency	ELF	1	3–30 Hz 100,000 km – 10,000 km	Communication with submarines	
Super low frequency	SLF	2	30–300 Hz 10,000 km – 1000 km	Communication with submarines	
Ultra low frequency	ULF	3	300–3000 Hz 1000 km – 100 km	Communication within mines	
Very low frequency	VLF	4	3–30 kHz 100 km – 10 km	Submarine communication, avalanche beacons, wireless heart rate monitors, geophysics	
Low frequency	LF	5	30–300 kHz 10 km – 1 km	Navigation, time signals, AM longwave broadcasting, RFID	
Medium frequency	MF	6	300–3000 kHz 1 km – 100 m	AM (medium-wave) broadcasts	
High frequency	HF	7	3–30 MHz 100 m – 10 m	Shortwave broadcasts, amateur radio and over-the-horizon aviation communications, RFID	
Very high frequency	VHF	8	30–300 MHz 10 m – 1 m	FM, television broadcasts and line-of-sight ground-to-aircraft and aircraft-to-aircraft communications. Land Mobile and Maritime Mobile communications	
Ultra high frequency	UHF	9	300–3000 MHz 1 m – 100 mm	Television broadcasts, microwave ovens, mobile phones, wireless LAN, Bluetooth, GPS and two-way rac such as Land Mobile, FRS and GMRS radios	
Super high frequency	SHF	10	3–30 GHz 100 mm – 10 mm	Microwave devices, wireless LAN, most modern radars, communications satellites	
Extremely high frequency	EHF	11	30–300 GHz 10 mm – 1 mm	Radio astronomy, high-frequency microwave radio relay, microwave remote sensing	
Terahertz	THz	12	300–3,000 GHz 1 mm – 100 μm	Terahertz imaging – a potential replacement for X-rays in some medical applications, ultrafast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, sub-mm remote sensing	

pure engineering

Stripline Circuit

- Stripline is a conductor sandwiched by dielectric between a pair of ground planes, much like a coax cable would look after you ran it over with your SUV.
- The insulating material of the substrate forms a dielectric.
- The width of the strip, the thickness of the substrate and the relative permittivity of the substrate determine the characteristic impedance of the strip which is a transmission line.
- To prevent the propagation of unwanted modes, the two ground planes must be shorted together. This is commonly achieved by a row of vias running parallel to the strip on each side
- An advantage of stripline is that fantastic isolation between adjacent traces can be achieved (as opposed to microstrip). The best isolation results when a picket-fence of vias surrounds each transmission line

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Microstrip Circuit

- A microstrip circuit uses a thin flat conductor that runs parallel to the ground plane.
- Microstrip can be made by having a strip of copper on one side of a PCB or ceramic substrate while the other side is a continuous ground plane.
- The width of the strip, the thickness of the insulating layer (PCB or ceramic) and the dielectric constant of the insulating layer determine the characteristic impedance.
- Microstrip is by far the most popular microwave transmission line, especially for microwave integrated circuits.
- The major advantage of microstrip over stripline is that all active components can be mounted on top of the board.

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CoPlanar Waveguide

- "Classic" coplanar waveguide is formed from a conductor separated from a pair of ground planes, all on the same plane, atop a dielectric medium (CPW).
- A variant of coplanar waveguide is formed when a ground plane is provided on the opposite side of the dielectric (GCPW).
- The advantage of coplanar waveguide is that active devices can be mounted on top of the circuit, like on a microstrip.

CoPlanar Waveguide (CPW)

Ground must extend at least 5x the "B" dimension on either side of trace "A".

CoPlanar Waveguide (Differential Pair)

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4 port Interdigital Capacitor

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Circular Spiral Inductor

Integrated Components Ð **Rectangular Spiral Inductor** INTERCEPT

Integrated Components E 0 **Butterfly Stub** 0 INTERCEPT

RF Schematic

RF Basics

- RF/Microwave circuits are designed to pass signals within the band of interest and filter those outside that range.
- Microwave signals are very sensitive and susceptible to signal noise.
- Via fences are recommended on both sides of a Coplanar circuit.
- When transmission lines are required to bend (change direction) due to routing constraints, use a bend radius that is at least 3 times the conductor width.
- When layout constraints required that a transmission line move to a different layer, it is recommended that at least two via holes be used for each transition to minimize the via inductance loading.

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RF Basics

- RF Transmission Lines Lines should be kept as far apart as possible, and should not be routed in close proximity for extended distances.
- Lines that cross on separate layers should have a ground plane keeping them apart.
- High-Speed Digital Signal Lines These lines should be routed separately on a different layer than the RF signal lines, to prevent coupling. Digital noise (from clocks, PLLs, etc.) can couple onto RF signal lines.

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RF Basics

- The recommended practice is to use a solid (continuous) ground plane on Layer 2, assuming Layer 1 is used for the RF components and transmission lines.
- For striplines and offset striplines, ground planes above and below the center conductor are required.
- Ground vias between layers should be added liberally throughout the RF portion of the PCB. This helps prevent accrual of parasitic ground inductance due to ground-current return paths.

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Reading List

- Transmission Line Design Handbook Brian C. Wadell (Artech House Publishers) – ISBN 0-89006-436-9
- HF Filter Design and Computer Simulation Randall W.Rhea (Noble Publishing Corp.) – ISBN 1-884932-25-8
- Partitioning for RF Design Andy Kowalewski PrintedCircuit Design Magazine, April, 2000.
- RF & Microwave Design Techniques for PCBs Lawrence M.Burns - Proceedings, PCB Design Conference West, 2000.

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Slang

Adult supervision

Management or business people. Often the best technology comes from the sandbox that has the least adult supervision.

Bart's head

Bart's head is the colloquial term for the waveform in the frequency domain of a CDMA signal as viewed on a spectrum analyzer. When operating correctly, it looks a lot like Bart Simpson's head. Square sides, kind of choppy on the top.

You might hear something like; "I looked at the Bart's head at the antenna port, and it rolls pretty sharply, I think the duplexer is tweaked".

Bazooka Joe Graph

A graph in a presentation or document that is so small it is rendered unreadable by the human eye alone. Refers to the hapless hero of tiny comic-strip fame. Often employed as a marketing tool in catalogs by vendors that don't want you to know exactly how much insertion loss that switch has.

Black box

When you don't have access to the schematic of a component or subsystem that is sealed up in a package that can't be opened, it's called a black box.

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Showstopper

A fundamental problem that blows the whole project out of the water.

Resources

- Microwaves 101.com http://www.microwaves101.com
- Transmission Line Design Handbook Brian C. Wadell (Artech House Publishers) ISBN 0-89006-436-9
- RF / Microwave PC Board Design and Layout Rick Hartley L-3 Avionics Systems
- Partitioning for RF Design Andy Kowalewski Printed Circuit Design Magazine, April, 2000.

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- RF Circuit Design Chris Bowick. Newnes Publishing (1982) ISBN 0-7506-9946-9
- Intercept Technology Inc. Pantheon www.intercept.com