Amateur Extra Class License Study Guide

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Compiled from; The ARRL Extra Class Manual – Eleventh Edition

Questions for use from 1 July, 2016 – 30 June, 2020

This study guide is meant to compliment the ARRL Extra Class Manual, not replace it.

Chapter 2 – Operating Practices

General Operating

Extra Class HF Frequencies

Frequency Selection

DXing – 2-3

E2C08 – The ARRL's QSL service handles both US-to-DX and DX-to-US QSL's, But not US-to-US cards because there would be too many and for which regular mail is available.

E2C05 – Many DX stations use the services of a QSL manager who confirms contacts and sends out responding QSL cards for a DX station.

DX Windows and Watering Holes

E2C06 – Dxing and contests on VHF and UHF bands take place in the "weak signal" allocations at the low end of the band.

Pileup Productivity – 2-4

2-5

E2C10 – If the stations are spread out over a few kilohertz, the DX station is probably working ***split***. Look for the DX station down a few kilohertz or more if the DX station is operating on a frequency unavailable to you, perhaps outside the U.S. band entirely. This practice separates the signals of the calling stations from the DX station, reducing interference and improving efficiency.

E2C11 – Give your full call sign or twice (using standard phonetics on phone) and then pause to listen for the DX station.

DXing Propagation

E2C12 – By learning how HF propagation works, you know that the MUF between your station and Europe is dropping. In response, change to a lower frequency.

Contesting – 2-6

2-7

E2C03 – By general agreement contesting does not take place on the 60, 30, 17 and 12 meter bands, giving non-contest operators room during busy weekend events.

E2C04 – Contacts via repeaters are usually not allowed, since the goal is to exercise the skill of the operators in making contacts without using an intermediate station.

Submitting a Contest Log – 2-7

E2C01 – You are encouraged to make contacts whether you intend to submit a log to the contest sponsors or not – no entry is required.

E2C07 – The Cabrillo format is a standard for organizing the information in a submitted contest log so that the sponsor can check and score the QSO's.

Using Spotting Networks – 2-8

2-9

E2C02 – The only way in which spotting networks may not be used is to ***self-spot***. That is announcing your own call sign and frequency on the spotting networks.

Remote Stations – 2-9

E2C13 – You must identify your transmissions according to the rules for operation that apply at the transmitter if they are different from those that apply where the operator is located.

Digital Mode Operating – 2-10

Packet Radio

2-11

Packet Cluster

E2D04 / E2D05 – These small satellites function as packet bulletin board store-and-forward systems. A terrestrial station can send a message through PACSAT by uploading it to the satellite for another station to download when the satellite is in view.

Automatic Packet Reporting System

E2D07 – The Automatic Packet Reporting System (APRS) is a messaging system that makes use of packet radio. It functions by using the AX.25 Amateur Packet Radio Protocol.

E2D08 – APRS stations transmit a beacon containing the stations location, weather conditions, and short text messages. The data is transmitted in an unnumbered information (UI) frame.

2-12

E2D11 – Position data is sent to the APRS network as latitude and longitude.

E2A14 – By adding the altitude data from a GPS receiver, a three-dimensional position can be obtained. This type of APRS system is frequently used to track the position of a high-altitude balloon or rocket in near real-time, aiding in its recovery and linking position with any sensor data being measured.

E2D10 – APRS networks can also be used to support public service or emergency communications by providing event managers and organizers continuously-updated location and other information from the APRS equipped station.

Amateur Satellites – 2-12

Understanding Satellite Orbits

2-13

E2A03 – One orbit is defined as one complete revolution about the Earth (***the orbital period***)

E2A13 – If the geosynchronous orbit is over the Earth's equator, the satellite appears to stay in the same position. This special type of orbit is called ***geostationary.***

E2A12 – Kepler's laws can be expressed mathematically, and if you know the values of a set of measurements of the satellite orbit (called ***Keplerian Elements***), you can calculate the position of the satellite at any time.

Orbital Mechanics – 2-14

E2A01 / E2A02 – The ***descending node*** is the point where the orbit crosses the equator traveling from north to south. When the satellite is within range of your location, it is common to describe the pass as either an ***ascending pass*** (traveling from south to north over your area) or a ***descending pass*** (traveling from north to south).

Faraday Rotation and Spin Modulation

2-15

E2A10 – You will notice the effect as a fairly rapid, pulsed signal fading. This condition is called ***spin modulation***.

E2A11 – Circularly polarized antennas will minimize the effect, just as they do for Faraday rotation.

Transponders – 2-15

2-16

E2A07 – A transponder can be thought of as a multimode repeater. Whatever mode is received is retransmitted.

E2A08 – Because all users must share the power output, continuous-carrier modes such as FM and RTTY generally are not used through amateur satellites and all users should limit their transmitting ERP (effective radiated power) to allow as many stations as possible to use the transponder.

E2A04 – The operating mode of a satellite identifies the uplink and downlink frequency bands that the satellite is using.

E2A05 – The letters in a satellite's mode designator specify the uplink and downlink frequency ranges.

E2A06 – The satellite mode designator U/V specifies that it receives signals on 435MHz – 438MHZ

E2A09 – The terms L band and S band specify the 23cm and 13cm bands.

Chapter 3 – Rules and Regulations

Operating Standards

Frequency and Emission Privileges

3-2

<u>E1A05</u> – The maximum power output allowed on 60 meters is 100 watts PEP effective radiated power relative to the gain of a half-wave dipole.

<u>E1A06</u> – The carrier frequency of a CW signal set to comply with FCC rules for 60 meter operation must be set at the center of the frequency channel.

<u>E1A07</u> – The 60 meter band requires transmission on specific channel, rather than on a range of frequencies.

<u>E1A14</u> – The maximum bandwidth for any transmission on 60 meters is 2.8kHz.

3-4 – Displayed Frequency – Managing Your Sidebands

<u>E1A01/E1A02</u> – On USB, it's prudent to set your carrier frequency no closer that 3kHz below the band edge and on LSB, no closer than 3kHz above the band edge.

<u>E1A03</u> – If your carrier is closer than 3kHz to the band edge – say 14.349MHz or 7.126MHz – your sidebands will be outside the band.

<u>E1A12</u> – A typical CW signal has a bandwidth of 50 – 150kHz, so setting the carrier frequency exactly on the band edge, such as 3500kHz, will result in your signal extending outside the band even if your displayed frequency is exactly accurate.

3-5 Automatic Message Forwarding

3-6

<u>E1A08</u> – If a message violates the FCC rules, the FCC holds the originating station primarily responsible.

<u>E1A09</u> – If you become aware that your station inadvertently forwarded a communication that violates FCC rules, you should immediately discontinue forwarding that message.

RACES Operation

<u>E1B09</u> – Any licensed amateur station may be operated in RACES, as long as the station is certified by the civil defense organization responsible for the area served.

<u>E1B10</u> – All amateur frequencies are available to stations participating in RACES operation.

3-7 – **Stations aboard Ships or Aircraft (FCC Section 97.11)**

E1A10 – You must have the radio installation approved by the master of the ship or the pilot in command of the aircraft.

E1A11 – Your FCC license is all that is needed. No other special license or permit is required to operate aboard ship or aircraft.

E1A13 – To operate from international waters (or air space) from a vessel or plane registered in the U.S. you must have an FCC-issued amateur license or reciprocal operating permit.

3-7 – **Station Restrictions**

Operating Restrictions

3-8

E1B08 – Where the interference from the amateur station is causing a sufficient amount of interference, the FCC can impose quiet periods on the amateur station on the frequencies that cause interference.

E1B01 - ***FCC Section 97.3(a)(42)*** defines a "***spurious emission***" as an emission on frequencies outside the necessary bandwidth of a transmission, the level of which may be reduced without effecting the information being transmitted.

E1B11 – For stations installed in 2003 or later, spurious emissions must be at least 43dB below the mean power of the fundamental signal.

3-8 – **Station Location and Antenna Structures**

Restrictions on Locations

E1B02 – If the land on which your station is located has environmental importance, or is significant in American History, Architecture or culture you may be required to take action as described in ***FCC Section 97.13(a)***

E1B04 – If your station will be located within the boundaries of an officially designated wilderness area, wildlife preserve, or an area listed in the National Register of Historical Places, you may be required to submit an Environmental Assessment to the FCC.

E1B03 – If your station is located within 1 mile of an FCC monitoring facility, you must protect that facility from harmful interference.

Restrictions On Antenna Structures

3-9

E1B06 – If your antenna is located near a public use airport, then further height limitations may apply. You must obtain approval from the FAA in such cases.

3-10 – **Station Control**

E1C07 – If you are present at the station and control its operation, that is local control.

Remote Control

E1C06 – Operating a station by remote control means that, the ***control point*** is no longer at the radio – it's where the control operator is.

E1C01 – The intermediary system that allows you to operate the radio without being in direct contact with it – that's the ***control link.***

E1C08 – If the control link malfunctions, ***FCC Section 97.213*** requires that backup control equipment should limit continuous transmissions to no more than 3 minutes.

3-12 **Automatic Control**

E1C02 – Defined in ***FCC Section 97.3(a)(6)*** as the use of devices and procedures for the control of a station when it is transmitting so that compliance with the FCC rules is achieved without the control operator being present at the control point.

E1C09 – When operating below 30MHz, 29.500MHz – 29.700MHz is the only available range for an automatically controlled repeater.

3-12

E1C10 – In addition to repeaters, retransmitting the signals of other amateur stations is prohibited only for ***auxiliary*** and ***space stations.***

E1C05 – Automatically controlled stations may only relay third-party communications as RTTY or data emissions and are never allowed to originate messages.

Amateur Satellite Service

E1D02 – It applies to amateur stations on satellites orbiting the Earth providing Amateur Radio Communications.

E1D04 – Amateur satellite service stations engaging in satellite communications that are on or within 50KM of the Earth's surface are called Earth stations.

3-13 **Telecommand and Telemetry**

E1D03 – The process of transmitting communications to a satellite to initiate, modify or terminate the various functions of a space station is called ***telecommand operations.***

E1D01 – ***Telemetry*** is the general term for any one-way transmission of measurements to a receiver located at a distance from the measuring instrument.

3-14 – Satellite Licensing and Frequency Privileges

E1D05 – Any licensed amateur station radio operator may be the control operator of a space station – no special license is required.

B1D10 – Any amateur station may be a satellite telecommand station subject to the restrictions of the control operator's license class.

E1D06 – A space station must have incorporated the ability for its transmitter to be turned off by telecommand.

E1D07 – A space station may only operate on the 17, 15, 12 and 10 meter bands and on portions of the 40 and 20 meter bands.

E1D08/E1D09 – Segments of the 2 meter, 70cm, 23cm, 13cm and some microwave bands are also available for space station operation.

E1D11 – Any amateur station can operate as an Earth station if the privileges of the license allow the operator to use the frequencies and modes on which the satellite operates.

3-14 – Volunteer Examiner Program

E1E03 – A Volunteer Exam Coordinator (VEC) is an organization that has entered into an agreement with the FCC to coordinate amateur license exams.

3-15 – Accreditation

E1E04 – The accreditation process is simply the steps that each VEC takes to ensure their VE's meet all FCC requirements to serve in the Volunteer Examiner Program

Exam Preparation

E1E02 – The set of all the questions available to be asked on an exam is called the question pool.

3-17 – Exam Session Administration

E1E01 – Every amateur radio license exam session must be coordinated by a VEC, and must be administered by a VE team consisting of at least three VE's accredited by the VEC coordinating the session.

E1E08 – VE's are prohibited from administering the exams to close relatives as defined by the FCC.

During The Exam

<u>E1E06</u> – All 3 VE's are responsible for supervising the exam session and must be present during the entire session, observing the candidates to ensure that the session is conducted properly.

<u>E1E13</u> – The VE's may monitor the station from a different location by using a real time video link.

<u>E1E07</u> – If any candidate fails to comply with a VE's instructions during the exam, the VE team should immediately terminate that candidate's exam.

<u>E1E05</u> – A score of 74% is the minimum to pass the exam.

<u>E1E12</u> – If any candidate did not pass all the exam elements needed to complete their license upgrade, then the examiners must return their applications to those candidates and inform them of the grades.

<u>E1E11</u> – After grading the exams of those candidates who do pass the exam, the entire VE team must certify their qualifications for new licensees and that they have complied with the VE requirements on their application forms and issue each a CSCE

3-17/3-18

<u>E1E09</u> – If the FCC determines that the VE has fraudulently administered or certified an exam, that VE can lose their amateur station license and have their privileges suspended.

3-18

<u>E1E10</u> – The VE team must submit the application forms and test papers for all the candidates who passed to the coordinating VEC within 10 days of the test session.

3-19 - **Miscellaneous Rules**

Auxiliary Stations

<u>E1F12</u> – Control operators of auxiliary stations must hold a Technician, General, Advanced or Extra class license.

External Power Amplifiers

<u>E1F11</u> – To receive a grant of certification, an amplifier must satisfy the spurious emission standards specified in ***<u>FCC Section 97.307(d)</u>*** or ***<u>(e)</u>*** when operated at full power or 1500w, whichever is less.

3-19

<u>E1F03</u> – Dealers may also sell non-certified amplifiers if they were purchased in used condition and resold to another amateur for use in their station.

3-20 - Line A and National Quiet Zones

E1F04 – An imaginary line, called Line A, runs roughly parallel to the south of the U.S. – Canadian border.

E1F05 – U.S. stations north of Line A may not transmit on the 420 – 430MHz band.

E1B05 – There is an area in Maryland, West Virginia and Virginia surrounding the National Radio Astronomy Observatory. This area is known as the National Radio Quiet Zone.

Business and Payment

E1F07 – You can send a message to a business over the air, to order something, as long as you don't do it regularly and as part of your normal income making activities.

E1C12 – No exception to the non-business rule is made for communications on behalf of nonprofit organizations.

3-20/3-21

E1F08 – Another broad prohibition is receiving compensation for communications via Amateur Radio – either being paid directly "for-hire" or in trade of some sort, such as equipment or services.

3-21 Spread Spectrum Operation

E1F09 – Spread Spectrum (SS) transmissions must not be used to obscure the meaning on any communications.

E1F10 – The FCC limits the maximum transmitter power for spread spectrum communications to 10 watts.

E1F01 – Operation using spread spectrum technologies is restricted to frequencies above 222MHz.

Non - U.S. Operating Agreements

E1C11 – European Conference of Postal and Telecommunications Administration (CEPT) radio-amateur license – allows U.S. amateurs to travel to and operate from most European countries and their overseas territories without obtaining an additional license or permit.

E1C13 – You must carry a copy of FCC Public Notice DA 11-221

3-21

E1C04 – International Amateur Radio Permit (IARP) – For operation in certain countries of Central and South America, the IARP allows U.S. amateurs to operate without seeking a special license or permit to enter and operate from that country.

3-22

E1F02 – Canadian amateurs operating in the U.S. may not transmit SSB below 14.150MHz even though they may do so from home.

E1F06 – If sufficiently good reasons are provided to the FCC, a Special Temporary Authority (STA) may be granted to provide for experimental amateur communications.

Chapter 4 – Electrical Principles

Radio Mathematics

4-2

E5C11 – Every point on a rectangular coordinate graph has two coordinates that identify its location, X and Y, also written (X,Y)

4-4 - Electrical and Magnetic Fields

4-5 – Electromagnetic Fields and Waves

E3A16 – The changing electric and magnetic fields create electromagnetic waves (i.e. radio waves) that propagate through space carrying both electric and magnetic energy.

E5D08 – The ***potential*** energy is shared between the electric and magnetic fields of the electromagnetic field, just as it is stored in electrostatic and electromagnetic fields.

E3A15 – The electric and magnetic fields of the wave are oriented at right angles to each other.

4-7 Polarization

E3A17 – It is also possible to generate electromagnetic waves in which the orientation of successive wave fronts rotates around the direction of travel – both the electric and magnetic fields. This is called ***circular polarization***.

4-8 – Principles of Circuits

Magnetic Energy Storage

4-9

E5D06 – The direction of the magnetic field is wrapped around the current at right angles to electronic current flow and can be determined by the ***left-hand rule***.

E5D07 – The strength of the magnetic field depends on the current and is stronger when the current is larger.

4-10 RC Circuit Time Constant Calculations

Equation 4.1

t=RC

t – Greek letter tau, represents the time constant

R – Total circuit resistance in Ohms

C – Capacitance in farads

Equation 4.2 (for a charging capacitor)

V(t)=E(1-$\boldsymbol{e}^{(-t/t)}$)

V(t) – voltage across the capacitor at time t

E – The applied voltage

T – Time in seconds since the capacitor began charging or discharging

e – The base for natural logarithms, 2.718

bolding indicates the e is raised to the power of (-t/*t*)

T – Greek letter tau, the time constant for the circuit, in seconds

Equation 4.3 (for a discharging capacitor)

V(t)=E($\mathbf{e}^{(-t/t)}$)

Bolding indicates the e is raised to the power of (-t/*t*)

4-12

E5B01 – From the calculations for a charging capacitor we can define the time constant of an RC circuit as the time it takes to charge the capacitor to 63.2% of the supply voltage.

E5B02 – From the calculations for a discharging capacitor we can also define the time constant as the time it takes to discharge the capacitor to 36.8% of its initial voltage.

4-13 RL Time Constant Calculations

Equation 4.4

t=L/R

Equation 4.5

I(t)=E/R x(1-$\mathbf{e}^{(-t/t)}$)

I(t) – Current in Amps at time t

E – Applied voltage

R – Resistance in Ohms

t – Time in seconds after the switch is closed

t – Greek letter Tau, time constant for the circuit in seconds.

4-15 – **AC Voltage – Current Relationships in Capacitors**

4-16

E5B09 – Current through a capacitor leads the applied voltage by 90 degrees

4-17

E5B10 – Voltage applied to an inductor leads the current through it by 90 degrees.

4-18 - Writing and Graphing Impedance Phase Angle

Impedance values are written in rectangular form as Z=R±***j***X where the reactance, X, can be positive (inductance+***j***X), or negative (capacitive-***j***X).

Example; The impedance 50-***j***25Ω consists of 50Ω of resistance and 25Ω of capacitive reactance.

E5C01 – In rectangular notation, capacitive reactance is represented by a ***–j***X (negative *j*X)

E5C03 - In polar coordinates an inductive reactance is represented by a ***positive*** phase angle.

E5C04 – In polar coordinates a capacitive reactance is represented by a ***negative*** phase angle.

E5C06 – In rectangular notation, 50Ω resistance in series with 25Ω capacitive reactance is represented as 50-j25

E5C09 – When using rectangular coordinates to graph the impedance of a circuit, the horizontal axis represents the resistive component.

E5C10 – When using rectangular coordinates to graph the impedance of a circuit, the vertical axis represents the reactive component.

E5C13 – The rectangular coordinate system is often used to display the resistive, inductive and/or capacitive reactance components of circuit impedance.

E5C12 – When plotting impedance using complex coordinates, any point that falls on the horizontal axis from) to 180 degrees is a ***pure resistance*** and has no reactive component.

4-18

E5C02 – Impedance can also be written in polar coordinates as |Z|∠Θ, where |Z| is the magnitude of the impedance and ∠Θ is its phase angle.

E5C08 – Impedance in polar coordinates are plotted with the right side of the horizontal axis indicating 0 degrees, the top half of the vertical axis indicating 90 degrees. And so forth.

E5C05 – Reactances change with frequency so a Phasor diagram assumes the frequency is the same for all values.

E5C07 – Phasors are a type of ***vector*** which is why any quantity that has both magnitude and direction. In the case of phasors, the direction is the angular component.

4-18 **Combining Resistance and Reactance**

4-19 – **Equation 4.6**

$Z = E/I = (E_R + jE_X)/I = E_R/I + j(E_X/I)$

4-20 – **Admittance and Susceptance**

The reciprocal (or inverse) of resistance is conductance (G)

E5B06 – The reciprocal of Impedance (Z) is ***admittance (Y)***

E5B12 – The reciprocal of reactance (X) is ***susceptance (B)***

E5B13 – The letter B is commonly used to represent susceptance.

Remember when taking the reciprocal of an angle, the sign is changed from positive to negative, or vice versa.

E5B03 – When converting the phase angle of a reactance to the phase angle of a susceptance, the sign (+ or -) is simply reversed.

E5B05 – When the magnitude of a reactance is converted to a susceptance, the magnitude of the susceptance is the reciprocal of the magnitude of the reactance. $|B|=1/|X|$

4-21 – **Calculating the Impedances and Phase Angle**

Rule #1; Impedances, resistances, and reactances in series add together

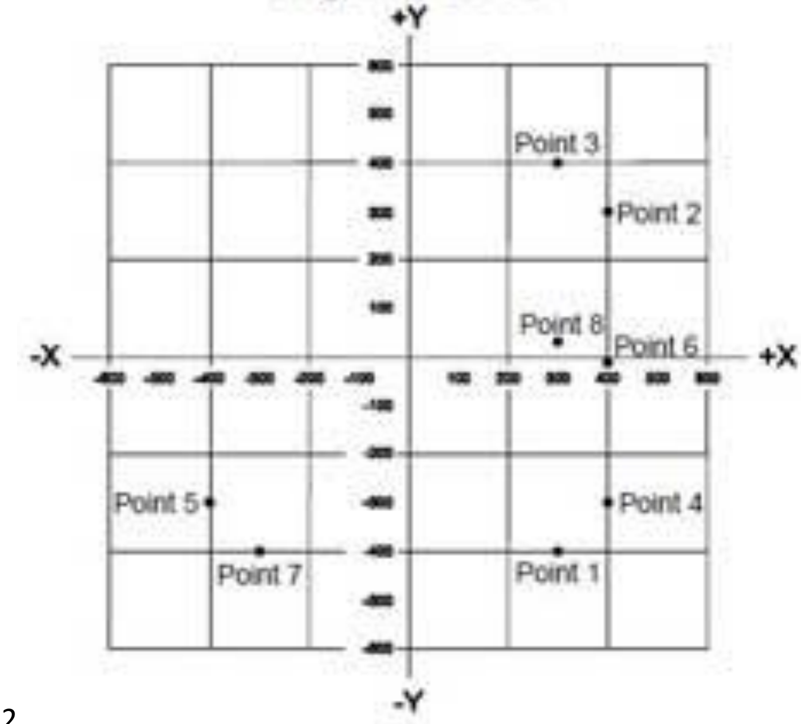
Rule #2; Admittance is the reciprocal of impedance (Y=1/Z), and the susceptance is the reciprocal of reactance (B=1/X). This changes the sign of the angle in polar form: Example $1/|Y|=\angle\ \Theta = |1/Y|=\angle -\Theta$

Rule #3; Admittances, conductances and susceptances in parallel add together.

Rule #4; Inductive and capacitive reactance in series cancel.

Rule #5; $1/j=-j$

Figure E5-2



4-22

E5C15 – Calculate the impedance of a circuit consisting of a 300Ω resistor in series with an 18 µH inductor at 3.505MHz.

Step 1 – Calculate the inductor's reactance.

$X_L = 2\pi FL$

$X_L = 2x3.14x3.505MHZx18\mu H = 400\Omega$

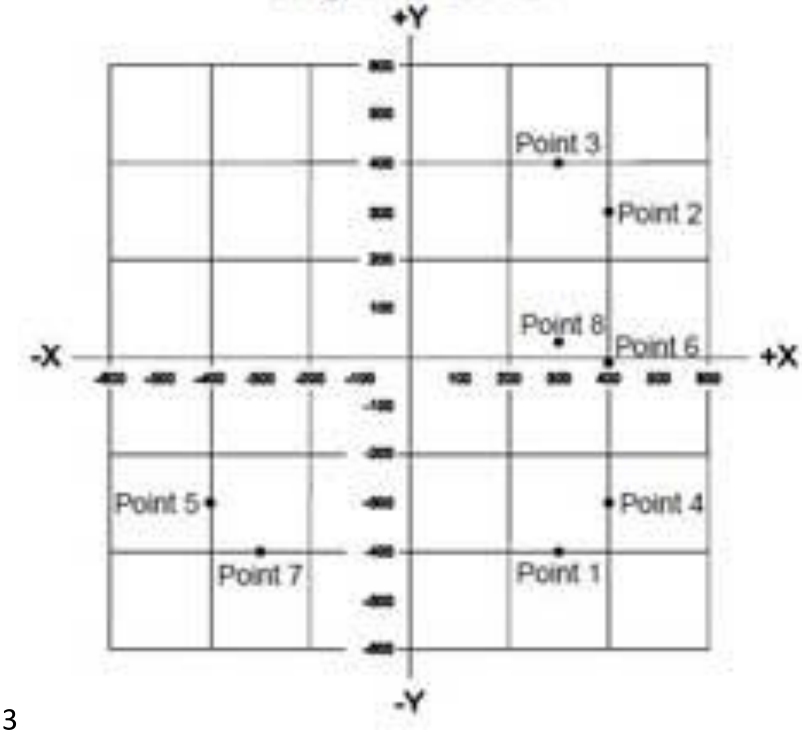
Step 2 – Use Rule #1 to add the resistance and reactance together.

$Z = 300\Omega + j400\Omega$

Step 3 – Locate the point of the graph, 300 units along the X axis and +400 units on the Y axis.

Answer – Point 3

Figure E5-2



4-23

<u>E5C14</u> – Calculate the impedance of a circuit consisting of a 400Ω in series with a 38 pf capacitor at 14MHZ.

Step 1 - Calculate the capacitor's reactance

X_C=1/2πfc

X_C=2x3.14x14MHzx38pf = -300Ω

(*Capacitive reactance is assigned a negative value*)

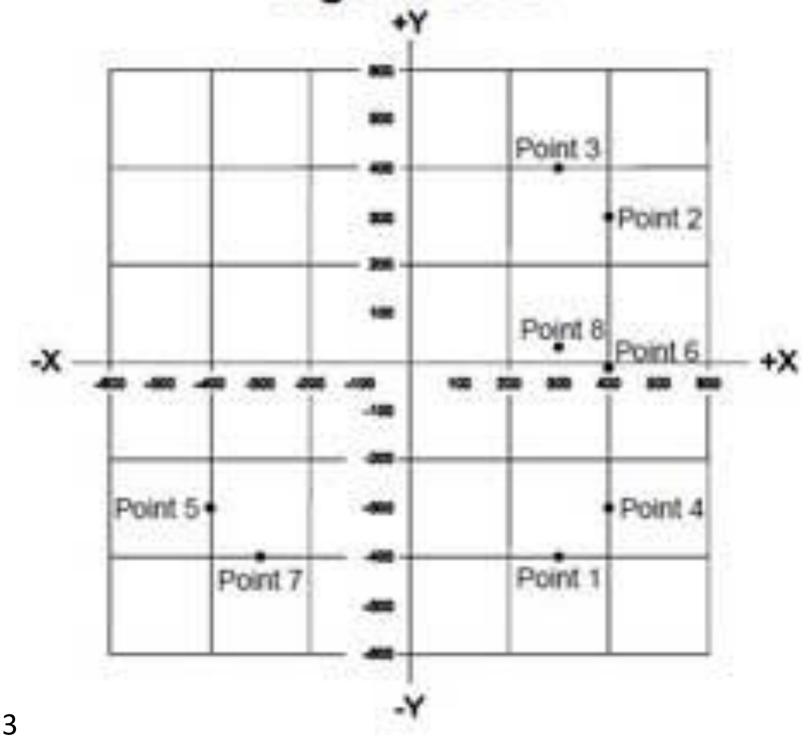
Step 2 – Use Rule #1 to add the resistance and reactance together.

Z=400Ω-*j*300Ω

Step 3 – Locate the point on the graph, 400 units along the horizontal axis and -300 units along the Y axis.

<u>Answer – Point 4</u>

Figure E5-2



4-23

<u>E5C16</u> – Calculate the impedance of a circuit consisting of a 300Ω resistor in series with a 19pf capacitor at 21.2MHz

Step 1 – Calculate the capacitor’s reactance.

$X_C = 1/2\pi fc$

X_C=2x3.14x19pfx21.2MHz

X_C = -400Ω

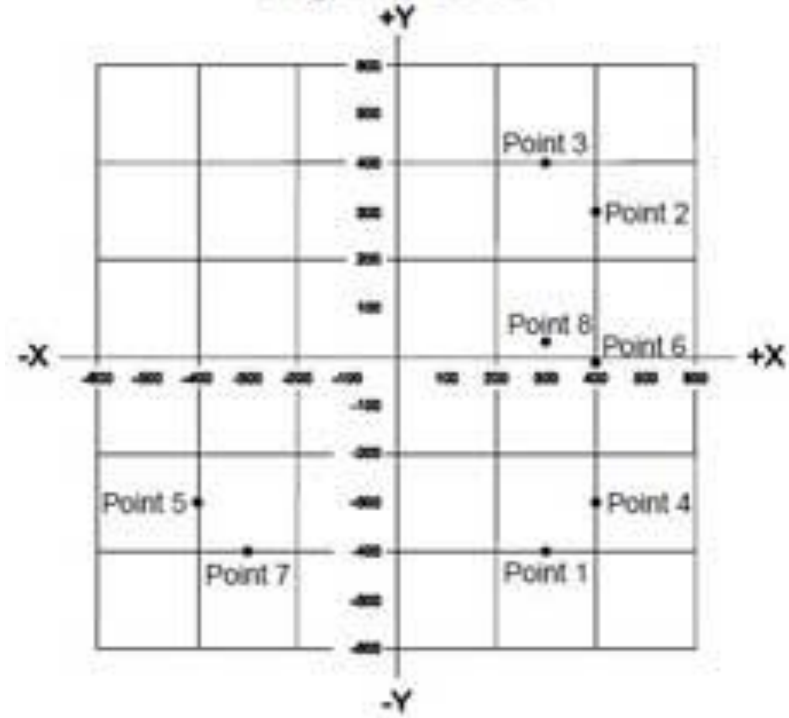
Step 2 – Use Rule #1 to add the resistance and reactance together

Z=300Ω-*j*400Ω

Step 3 – Locate the point on the graph 300 units along the X axis and -400 units on the Y axis.

<u>Answer – Point 1</u>

Figure E5-2



4-24

<u>E5C17</u> – Calculate the impedance of a circuit consisting of a 300Ω resistor in series with a 0.64µH inductor and an 85pf capacitor at 24.9MHz

Step 1 – Calculate the capacitor's reactance

X_C=1/2πfc = 2x3.14x24.9MHzx0.85pf = -75Ω

Step 2 – Calculate the inductor's reactance

X_L=2πfl = 2x3.14x24.9MHzx0.64µH = 100Ω

Step 3 – Use Rules #1 and #4 to add the resistance and reactances together.

Z=300+-*j*75Ω+*j*100Ω = 300+*j*25Ω

Step 4 – Locate the point on the graph that is 300 units along the X axis and +25 units along the Y axis.

<u>Answer – Point 8</u>

4-24

E5B07 – What is the phase angle between voltage and current in a series RLC circuit if XsubC is 500Ω, R is 1KΩ and XsubL is 250Ω

Step 1 – Use =1000+***j***250Ω-***j***500Ω = 1000-***j***250Ω

Step 2 - Convert to polar form

R = square root of $(1000)^2 + (-250)^2$ = 1031

Θ = tan-1(-250/1000) = -14 degrees

Z=1031∠-14 degreesΩ

Step 3 – The phase angle is equal to the angle of the impedance: Θ=-14 degrees. Since the phase angle is from voltage to current, the negative angle indicates that voltage lags the current.

E5B08 – What is the phase angle between voltage and current in a series RLC circuit if X_C=100Ω, R=100Ω and X_L=75Ω

Step 1 – Use Rule #1 and #4 to add the resistance and reactance

Z=100 + ***j***75Ω –***j***100Ω = 100-***j***75Ω

Step 2 Convert Z to polar form

R=square root of $(100)^2 + (-25)^2 = 103$

Θ=tan-1(-25/100)

Z=103∠-14degrees

Step 3 The phase angle is equal to the angle of the impedance: Θ=-14degrees. Since the phase angle is from voltage to current, the negative angle indicates that voltage lags the current.

4-25

E5B11 – What is the phase angle between voltage and current in a series RLC circuit if X_C=25Ω, R=100Ω and X_L=50Ω

Step 1 Use Rules #1 and #4 to add the resistances and reactances together.

Z=100-*j*25+*j*50 = 100+*j*25

Step 2 Convert Z to polar form

R=square root of $(100)^2 + (25)^2 = 103$

ϴ=103∠14degrees

Step 3 – The phase angle is equal to the angle of impedance: ϴ=14degrees. Since phase angle is from voltage to current, the positive angle indicates that voltage leads current.

4-25 Reactive Power and Power Factor

Definition of Reactive Power – Electrical power is equal to the RMS values of current multiplied by voltage.

Equation 4.7 – P=IE

4-26

E5D09 – Only the resistive part of the circuit consumes and dissipates power as heat.

E5D14 – The apparent power in an inductor or capacitor is called ***reactive power*** or ***nonproductive, wattles power***.

Definition and Calculation of Power Factor

Equation 4.8

For a series circuit – $P=I^2xR$ (where I is the RMS current)

Equation 4.9

For a parallel circuit – $P=E^2/R$ (where E is the RMS voltage)

Equation 4.10

$PF=P_{REAL}/P_{APPARENT}$

Equation 4.11

$P_{REAL}=P_{APPARENT}$ x PF

E5D10 – The true power of an AC circuit where the voltage and current are out of phase can be determined by ***multiplying the apparent power times the power factor.***

4-27

Equation 4.12

Power Factor=cosΘ

The power factor can be calculated from the phase angle by taking the cosine of the phase angle. PF is positive whether the phase angle is negative or positive.

Example 4.12

E5D11/E5D15/E5D16 – What is the power factor for an R-L circuit having a phase angle of 30degrees? 45degrees? 60degrees?

PF for phase angle of 30degrees = **0.866**

PF for phase angle of 45degrees = **0.707**

PF for phase angle of 60degrees = **0.50**

E5D12 – Suppose you have a circuit that draws 4 amperes of current when 100 vac is applied. The power factor for this circuit is 0.2. What is the real power (how many watts are consumed) for this circuit.

Start by calculating apparent power by using Equation 4.7

$P_{APPARENT}$=100v x 4A = 400va

Real power is then calculated using Equation 4.11

P_{REAL}=400va x 0.2 = **80watts**

4-27/4-28

E5D13 – How much power is consumed in a circuit of a 100Ω resistor in series with a 100Ω inductive reactance and drawing 1 ampere of current.

Because only the resistance draws power;

$P_{REAL}=I^2 \times R = (1A)^2 \times 100\Omega$ = **100watts**

4-28

E5D17 – How many watts are consumed in a circuit having a power factor of 0.6 if the input is 200 vac at 5 amperes

Step 1 – Find apparent power by using Equation 4.7

PsubApparent = IE = 5A x 200v = 1000va

Step 2 – Multiply by the power factor as in Equation 4.11

$P_{REAL}= P_{APPARENT} \times PF$ = 1000 x 0.6 = 600watts

E5D18 – How many watts are consumed in a circuit having a power factor of 0.71 if the apparent power is 500va

Use Equation 4.11 to find PsubREAL

$P_{REAL} = P_{APPARENT}$ x FP = 500va x 0.71 = **355watts**

4-28

Resonant Circuits

E5A02 – Whether the components are connected in series or parallel, we say the circuit is resonant or is at resonance when the inductive reactance is the same as the capacitive reactance.

4-29 – Calculation of Resonance

Equation 4.13

Fr = 1/2π square root of (LC)

E5A14 – What frequency should the signal generator in figure 4.25 be tuned to for resonance if the resistor is 22Ω, the coil is 50mH and the capacitor has a value of 40pF?

50μH = 50 x 10 to the -6

40pF = 40 x 10 to the -2

Fr = 1/2x3.14 square root (50x10 to the -6) x (40 x 10 to the -2) = 3.56x10 to the 6 = **3.56MHz**

4-30

E5A16 – Calculating the resonant frequency of a parallel circuit is exactly the same as for a series circuit. For example; What is the resonant frequency of a parallel RLC circuit if R=33Ω, L=50μH and C=10pF?

Fr = 1/2π times the square root of (50 x 10 to the -6) x (10 x 10 to the -12) = 7.12 x 10 to the 6 = **7.12MHz**

Equation 4.15

Stored Energy in Resonant Circuits

E5A01 – The currents that flow back and forth between the inductor and the capacitor to exchange the stored energy are maximum at resonance.

4-31

Impedance of Resonant Circuits versus Frequency

E5A03 – With the voltage across the inductor and capacitor canceling each other, the only impedance presented to the signal generator is that of the resistance, R

E5A05 – The magnitude of the current at the input of a series RLC circuit ***will be at maximum*** as the circuit goes through resonance.

E5A06 – At resonance, the circulating currents will be at maximum, limited only by resistive losses in the components.

4-32

E5A08 – In both a series resonant circuit and a parallel resonant circuit, both the current and voltage are in phase.

4-32 – Q of Components and Circuits

The ***quality factor*** is called **Q**

One definition of Q is the ratio of reactance to resistance.

E5A15 – The lower the components resistive losses, the higher the Q

Equation 4.16

$Q=X/R$ or $Q=X_L/R_L$ or $Q=X_C/R_C$

Equation 4.16

$Q_{SERIES} = 1/R$ times the square root of L/C

$Q_{PARALLEL} = R$ times the square root of C/L

Knowing the XsubL = XsubC at resonance, Q can be computed just knowing either the reactance of either the inductor or the capacitor at the resonant frequency.

E5A09 – $Q_{SERIES} = X/R$

E5E10 – $Q_{PARALLEL} = R/X$

4-33

E5A13 – The higher the Q becomes, the higher the voltages and currents.

Q and Resonant Circuit Bandwidth

Equation 4.17

Δf=fr/Q

Where; Δf = the half power bandwidth

Fr = the resonant frequency of the circuit

Q = the circuit Q

E4B15 – The higher the Q, the sharper the frequency response of a resonant circuit will be whether it is series or parallel.

4-33/4-34

E5A11 – Calculate the half power bandwidth of a parallel resonant circuit that has a resonant frequency of 7.1MHz and a Q of 150. The half power bandwidth is found by using Equation 4.17

Δf=fr/Q = 7.1MHz/150 = 47.3x10 to the 3Hz = ***47.3kHz***

E5A12 – What is the half power bandwidth of a parallel resonant circuit that has a resonant frequency of 3.7MHz and a Q of 118

Δf = fr/Q = 3.7MHz/118 = ***31.4kHz***

4-34

E5A17 – As Q of such an impedance matching circuit increases, the internal voltages and currents increase and the bandwidth over which the impedance is matched decreases, just like that of a resonant circuit.

Components at RF and Microwave Frequencies

E5D01 – As the frequency increases, the effective area gets smaller as the current is confined to regions closer to the surface of the wire.

Self Resonance

Because of ***parasitic inter-turn capacitance*** – very small capacitances that exist between turns of an inductor – the inductor can become a ***self-resonant*** circuit at some sufficiently high frequency.

4-35

Effects of Component Packaging at RF

E5D05 – In circuits operating at VHF and higher frequencies, including high speed digital circuits, this inductive reactance can become significant and increases with frequency, making the circuit behave in unexpected (and usually unwanted) ways.

E5D02 – Good design and construction practice at these frequencies is to minimize the effects of lead inductance by using surface-mounted components or trimming the leads to be as short as possible.

E5D04 – This phase shift can be very difficult to control and leads to oscillation and uneven frequency response at microwave frequencies.

E6E11 – The dual in-line package (DIP) features two rows of pins spaced 0.1 inch apart, with the rows form 0.3 to 0.6 inch apart along opposite sides of a rectangular plastic or ceramic body.

E6E02 – Since the pins are inserted in holes in the printed-circuit board and extend through the board to be soldered on one or both sides of the board, the DIP is an example of a ***through-hole component***.

E6E10 – The entire assembly is heated until the solder paste melts and makes the permanent connection, holding the component to the board.

E6E12 – Some types of ceramics have both properties of high insulation and conducting heat well, and are commonly used for packages of high-power RF IC's and transistors.

4-36

E6D06 – Powdered iron cores generally have better temperature stability and maintain their characteristics at higher temperatures.

E6D05 – Ferrite cores generally have higher permeability values however, so inductors made with ferrite cores require fewer turns to produce a greater inductance.

E6D04/E6D14 – Ferrite cores, the most common, have a high relative permeability and ***increase inductance*** as the core is inserted. Brass cores, another common slug material, has a low relative permeability and ***causes a reduction in inductance*** when inserted.

E6D12 – When using transformers of any sort, it is important to avoid exceeding the core's ability to store magnetic energy, an effect called ***saturation***.

E6D17 – When saturation occurs, the transformer can no longer supply power to the output circuit and the output waveform becomes distorted, generally harmonics and other distortion products.

E6D15 – A transformer's core will contain some magnetic energy from ***magnetizing current*** in the primary winding even if no load is connected to the secondary.

4-37 – Core Shape

E6D10 – Nearly all of the toroidal inductor's magnetic field is contained within the toroid core.

E6D07 – Toroidal inductors are used in circuits that involve frequencies from below 20Hz to around 300MHz

4-37 Calculating Inductance

4-38 – Equation 4.18

L(for powdered iron cores)= A_L x N^2/10000

Where; L = inductance in µH

A_L = Inductance index, in µH per 100 turns

N = Number of turns

Equation 4.19

N = 100 times the square root of L/A_L

E6D01 – Suppose you want to know how many turns to wind on a T-50-6 core to produce a 5µH inductor? (The AsubL value = 40)

4-39 – Equation 4.20

N = 100 times the square root of L/A_L

N = 100 times the square root of 5µH/40

N = 100 times the square root of 0.125 = 35 turns

4-39 – Equation 4.20

L(for ferrite cores) = A_L x N^2/1000000

Where; L = inductance in mH

A_L = inductance index in mH per 100 turns

N = number of turns

Equation 4.21

N = 1000 times the square root of L/A_L

E6D11 - How many turns must we wind on a T-50-43 core to produce a 1-mH inductor? (AsubL=523)

N = 1000 times the square root of L/AsubL

N = 1000 times the square root of 1/523 = 1000 times the square root of 1.91x10 to the -3

N = 43.7 turns

E6D09 – A ***ferrite bead*** is a very small core with a hole designed to slip over a component lead. These are often used as suppressors for VHF and UHF oscillations at the input and output terminals of HF and UHF amplifiers.

Chapter 5 – Semiconductor Devices

Materials

5-2

E6A02 – Semiconductors made with materials that have an extra or ***free electron*** are called ***N-type***.

5-3

E6A04/E6A15 – Semiconductors made with material that have a hole to accept an electron are called ***P-type*** and are made with ***acceptor impurities***.

E6A16 – Free electrons are the ***majority charge carriers*** in N-type semiconductors.

Diodes

5-4

If the positive terminal is connected to the N-type material and the negative terminal is connected to the P-type material the diode is ***reversed bias***. The positive charge attracts the electrons and the negative charge attracts the holes pulling both away from the junction.

5-5

E6B07 – The maximum average forward current is the highest average current that can flow through the diode in the forward direction for a specified ***maximum allowable junction temperature***.

Schottky Barrier Diodes

E6B08 – If a PN-junction P-type material is replaced with a metal layer, A Schottky Barrier is created which has similar rectifying properties but with a lower forward voltage than an all semiconductor junction.

E6B02 – The Schottky Barrier Diode's forward voltage is 0.2 to 0.5v, compared to the 0.6 to 0.7v for silicon junction PN-junction diodes.

Point-Contact Diodes

5-6

E6B09 – Point-contact diodes are generally used as UHF mixers and as RF detectors at VHF and below.

Hot Carrier Diodes

E6B06 – hot-carrier diodes are often used in mixers and detectors at VHF and UHF.

5-6 – **Zener Diodes**

E6B01 – Since the current in the avalanche region can change over a wide range while the voltage stays practically constant, this kind of diode can be used as a voltage regulator.

5-7 – **Tunnel Diodes**

E6B03 – Negative resistance means that when the voltage across the diode increases, the current decreases. This property makes the tunnel diode capable of amplification and oscillation

Varactor Diodes

E6B04 – ***Variable capacitance diodes*** and ***varactor diodes*** (variable resistance diodes) are designed to take advantage of this property, creating voltage-controlled capacitors.

5-8 - **PIN Diodes**

E6B05 – A large region of intrinsic material is the characteristic of a PIN diode that makes it useful as an RF switch or attenuator.

E6B11 – A PIN diode uses the forward DC bias current to control the attenuation of RF signals.

E6B12 – One common use for PIN diodes is an RF switch.

5-9 - **Bipolar Transistors**

E6A07 – The change in collector current with respect to base current in a bipolar transistor is called the ***beta***.

E6A05 – The change of collector current with respect to the emitter current in a bipolar transistor is called the ***alpha***.

5-10

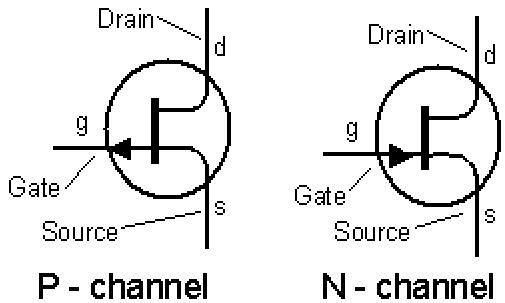
E6A08 – The ***alpha cutoff frequency*** is the frequency at which the current gain of a transistor decreases the 0.707 times its gain at 1 kHz.

Field Effect Transistors

JFET

E6A17 – The terminals that control resistance between the source and drain are called ***gates***.

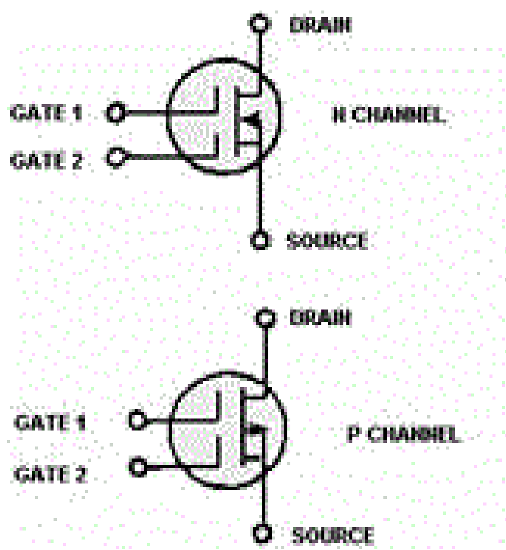
E6A11 – The schematic symbol for the two JFET types are illustrated in Figure 5.20



5-11

E6A14 – The gate terminal is always reversed biased, so very little current flows in the gate terminal and the JFET has very high input impedance – unlike the bipolar transistor which has much lower input impedance.

E6A10 – The schematic symbols for N-channel and P-channel MOSFET's are shown in Figure 5.22



E6A12 – Nearly all the MOSFETs manufactured today have built-in gate –protective zener diodes. Without this provision the gate insulation can be easily punctured by small static charges on the user's hand or by the application of excessive voltages to the device.

Enhanced and Depletion-Mode FETs

E6A09 – A depletion-mode device exhibits a current flow between source and drain when no gate voltage is applied.

5-12 – RF Integrated Devices

E6E08 – Voltage from a power supply is normally furnished to the most common type of monolithic microwave integrated circuit (MMIC) ***through a resistor and/or RF choke to the output lead.***

5-12/5-13

E6E06 – MMIC devices have well-controlled operating characteristics such as gain, noise figure and input/output impedance, requiring only a few external components for proper operation.

5-13

E6E04 – As "building blocks", MMICs can generally simplify an amplifier design for circuits at UHF and microwave frequencies because the circuits and the IC input and output impedances are all close to 50Ω.

E6A01/E6A03 – RF transistors and MMICs can operate well into the microwave range by using ***gallium arsenide (GaAs) and gallium nitride (GaN)***.

E6E07 – Circuits built using MMICs generally employ ***microstrip construction techniques***.

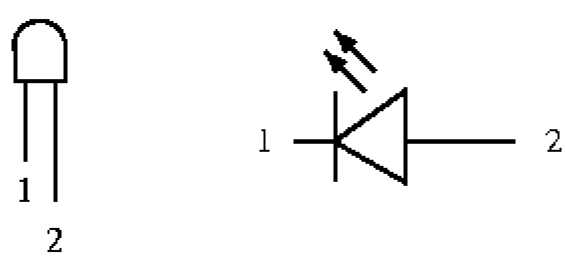
E5D03 - Microstrip is defined as – ***Precision printed circuit conductors over a ground plane that provide constant impedance interconnects at microwave frequencies.***

5-14 – Display Devices

Light Emitting Diodes

E6B13 – ***Light emitting diodes (LEDs)*** are designed to emit light when they are forward biased so that current passes through their PN junctions.

E6B10 – The schematic symbol and typical case style for the LED are shown in Figure 5.25



5-15 – Liquid Crystal Displays

E6F13 – The combination of filters and the helical crystal structure allows light to pass through the filters with the proper polarization and the display appears transparent.

E6F14 – They may also be difficult to view through polarized glasses.

5-16 **Charge-Coupled Devices**

E6E01 – A ***charge-coupled device (CCD)*** is a special type of integrated circuit that combines analog and digital signal handling capabilities. It does this by ***sampling an analog signal and passing it, in stages, from the input to the output.***

5-17 – **Digital Logic**

E7A01 – The logical function of a particular element may be described by listing all possible combinations of input and output values in a ***truth table***. Such a list of all combinations and their corresponding outputs characterize, or describe, the functions of any digital device.

5-18 – **One-Input Elements**

E6C11 – There are two logic elements that have only one input and one output: ***the noninverting buffer*** and the ***inverter*** or ***NOT circuit***.

The OR Operation

E7A08 – The OR gate will have a 0 output only when all inputs are 0

5-18/5-19 – **The NAND Operation**

E6C08/E7A07 – The NAND gate produces a 0 at its output only when all inputs are 1. In Boolean notation, NAND is usually represented by a dot between the variables and a bar over the combination.

5-19 – **The NOR Operation**

E6C10 – The NOR operation produces a 1 output only when all of its inputs are 0.

The Exclusive NOR Operation (XOR)

E7A09 – The XOR operation results in an output of 1 if only one of its inputs are 1, but if both of its inputs are 1, then the output is 0. Inverting the XOR function results in an Exclusive NOR (XOR).

Positive and Negative-True Logic

E7A11/E7A12 – ***Positive*** or ***positive-true logic*** uses the highest voltage level (HIGH) to represent a binary 1 and the lowest voltage level (LOW) to represent a binary 0. If the opposite representation is used (HIGH=0 and LOW=1), that is ***negative*** or ***negative-true logic***.

5-20 – **Tri-State Logic**

E6C04 – In digital circuits it is common for many ICs to be connected in parallel on a ***data bus*** or ***address bus*** to share data and addressing information.

E6C03 – ICs with this ability are referred to as tri-state logic in which an output can be HIGH, LOW or high-impedance.

5-21 – **Flip-Flops**

E7A01 – The term ***bistable*** means that the circuit has two stable states and it can stay in either state indefinitely.

Dynamic versus Static Inputs

5-22

E7A03 – The flip-flop thus provides one complete output pulse for every two input pulses, dividing the input signal's frequency by two.

E7A04 – Two such flip-flops could be connected sequentially to divide the input signal by four.

One-Shot or Monostable Multivibrator

E7A06 – When triggered, it switches to the unstable state and then returns after a set time to its original stable state.

Equation 5.3

$T=1.1RC$

Where; R=Resistance in Ohms

C=Capacitance in farads

T=Time in seconds

5-23 – **Astable Multivibrator**

E7A05 – an ***astable*** or ***free-running multivibrator*** is a circuit that continuously switches between two unstable states.

Equation 5.4

$F=1.46/C_1\,[R_1+(Z x R_2)]$

Where; R=resistance in ohms

C=Capacitance in farads

Dividers and Counters

E7A02 – A ***decade counter*** IC produces one output pulse for every 10 input pulses.

5-24 - **TTL Characteristics**

E6C07 – A pull-up or pull-down resistor is connected to the positive or negative supply line used to establish a voltage when an input or output is an open circuit.

5-25 – **CMOS Characteristics**

<u>E6A13</u> – Complementary Metal-Oxide Semiconductor (CMOS) devices are composed of N-channel and P-channel FETs combined on the same substrate.

<u>E6C05</u> – When a CMOS gate is not switching, it draws very little power.

<u>E6C06</u> – The switching threshold for CMOS inputs is approximately half the supply voltage. The wide range of input voltages gives the CMOS family great immunity to noise.

BiCMOS Logic

<u>E6C12/E6C13</u> – Bipolar and CMOS technology each have certain advantages, combining them in a single IC creates devices that can operate with the speed and low output impedance of bipolar transistors and the high input impedance and reduced power consumption typical of CMOS.

5-26 – **Programmable Logic**

<u>E6C09</u> – Programmable Logic Devices (PIDs) are single ICs that consist of thousands of logic gates, sequential logic, switches, registers and other complex functions up to and including microprocessors.

<u>E6C14</u> – Whether a PLD or Programmable Gate Array (PGA) is used, it is possible to create extremely complex functions in the single IC that operates at very high speed.

5-27 – **The Photovoltaic Effect**

Calculating Resistivity of a Material

Equation 5.5

$R = pl/A$

Where; p = the lower case Greek letter rho, representing the resistivity of the material.

l = length of the material

A = Cross-sectional area of the material

R= Resistance

<u>Conductivity</u> is the reciprocal of ***<u>resistivity</u>*** and ***<u>conductance</u>*** is the reciprocal of ***<u>resistance</u>***.

Equation 5.6

$\sigma = 1/p$

Where; σ = lower case Greek letter sigma, representing the conductivity.

p = the lower case Greek letter rho, representing the resistivity of the material.

Equation 5.7

G=1/R

G=Conductance

5-27

E6F02 – The conductivity of the material is increased and the resistivity is decreased.

E6F01 – Materials that respond to the photoconductive effect are said to exhibit photo conductivity.

5-28

E6F06 – The photoconductive effect is more pronounced and more important in crystalline semiconductor materials than in ordinary metal conductors.

Optoelectronic Components

Optocouplers and Optoisolators

E6F03 – An ***optocoupler*** or ***optoisolator*** is an LED and a phototransistor sharing a single IC package.

E6F08 – Optoisolators provide a very high degree of insulation between the input (LED) and the output (phototransistor). There is no current flow between the input and output terminals. For this reason they are often used when 120vac circuits are to be switched under the control of low-power digital signals.

5-29

E6F07 – By combining an optocoupler with power transistors, the functions of an electromechanical relay can be implemented by solid state components. The resulting solid-state relay (SSR) can operate much faster than an electromechanical relay and can be controlled directly by digital circuits.

The Optical Shaft Encoder

E6F05 - A plastic disc with a pattern of alternating clear and black radial bands rotates through a gap between emitters and detectors. By using an array of emitters and two detectors, a microprocessor can detect the rotation direction and speed of a wheel.

Photovoltaic Cells

E6F12 – If a PN junction is exposed to light, photons will be absorbed by the electrons in the semiconductor material.

5-30

E6F04 – The current represents the conversion of light energy from the photons to electrical energy carried by the electrons in the circuit. This is the ***photovoltaic effect***.

5-30

E6F10/E6F11 – A fully illuminated PV cell made of silicon, the most commonly used material for PV cells, develops an open-circuit voltage of approximately 0.5V

E6F09 – The amount of current such a cell can produce is determined by the degree of illumination and the ***conversion efficiency*** of the material – the relative fraction of light energy that is converted to electrical energy in the form of current.

Chapter 6 – Radio Circuits and Systems

Amplifiers

Discrete Device Amplifiers

Basic Circuits

6-3 – **Common Emitter Elements**

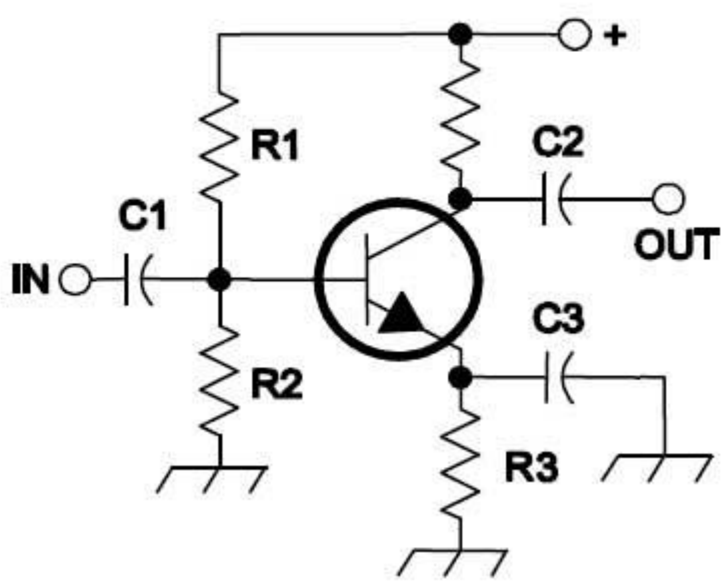
E7B12 – You can recognize the common – emitter circuit by the value for resistance in the emitter circuit (R3) being much smaller (or even absent) that that in the collector circuit (R4), or the emitter resistor being bypassed with a capacitor (C3).

E7B10 – R1 and R2 form a voltage divider to provide a stable operating point. This technique is called ***fixed bias***.

E7B11 – One solution is to add resistance in the emitter circuit (R3) to create ***degenerative emitter feedback*** or ***self-bias***.

E7B15 – The resulting balancing act stabilizes the transistor's operating point and prevents thermal runaway.

Figure E7-1



6-5 – **Common-Collector or Emitter Follower Circuit**

E7B13 – Without an R_L attached, R3 also acts as the emitter load resistor.

6-6 – **Similarities to Vacuum Tubes**

E7B18 – Grounded-Grid: Input signal applied to cathode, no current gain, ***low input impedance*** matches well to 50Ω feed line, grounded grid reduces need for neutralization.

OP AMP Amplifiers

E7G12 – The ***operational amplifier*** or ***op amp*** is a high gain, ***direct coupled***, ***differential*** amplifier that amplifies DC signals as well as AC signals.

6-7 – **Op Amp Characteristics**

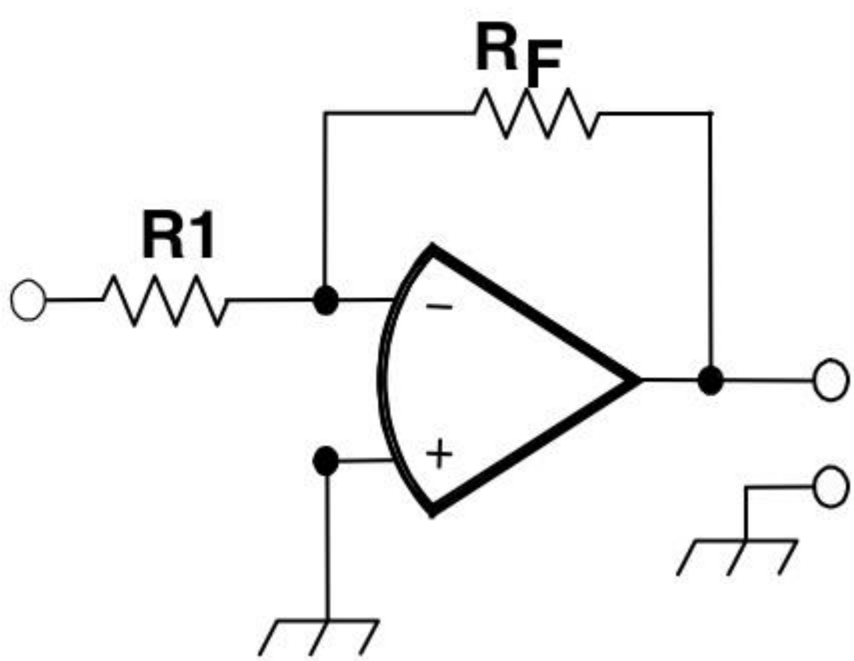
E7G01/E7G03/E7G08 – Infinite input impedance, zero output impedance, infinite voltage gain, flat frequency response within its frequency range, and zero output when the input is zero.

6-7/6-8

E7G04 – The op amp's ***input – offset voltage*** between the amplifier's inputs will produce a zero output voltage assuming the amplifier is in a closed-loop circuit.

6-8 – **Basic Amplifier Circuits**

Figure E7-4



6-9 **<u>Example 6.1</u>**

<u>E7G10</u> – Using the above figure, what is the voltage gain if R1 = 1800Ω and R_F=68kΩ.

$|A_V|$ = R_F/R1 = 68000/1800 = 38

<u>Example 6.2</u>

<u>E7G07</u> – What is the voltage gain if R1 = 10Ω and R_F=470Ω

$|A_V|$ = R_F/R1 = 470Ω/10Ω = 47

<u>Example 6.3</u>

<u>E7G11</u> – What is the voltage gain if R1 = 3300Ω and R_F=47kΩ

$|A_V|$ = R_F/R1 = 47000Ω/3300Ω = 14

<u>Example 6.4</u>

<u>E7G09</u> – What will the output voltage be if R1 = 1000Ω and R_F=10kΩ and the input voltage = 0.23v

$|A_V|$ = R_F/R1 = 10000Ω/1000Ω = 10

The circuit is inverting, so V_{OUT} = $-A_V$

V_{IN}= -10(0.23) = -2.3V

6-9 – **Comparators**

<u>E6C02</u> – The comparator changes its output state depending on whether the unknown voltage is above or below the threshold.

6-10

<u>E6C01</u> – comparator circuits also use hysteresis to prevent "chatter" – the output of the comparator switching rapidly back and forth when noise causes the input voltage to cross the setpoint threshold repeatedly. The unstable output can be confusing to the circuits acting on the comparator output.

Classes of Operation

Class A

<u>E7B04</u> – In Class A operation, bias is adjusted so that the amplifier's operating point is halfway between saturation and cutoff regions.

6-11 – **Class B**

E7B06 – Class B amplifiers are often used at audio frequencies by connecting two tubes or transistors in a ***push-pull*** circuit. This reduces the amount of distortion in the output and will reduce even-order harmonics.

Class AB

E7B01 – It operates for between 180 and 360 degrees of the signal cycle.

Class C

E7B07 – Using a Class C amplifier for SSB or digital signals would result in too much distortion and the output signal would occupy excessive bandwidth.

Switching or Switchmode Classes

E7B14 – The power transistor acts entirely as a switch, either completely saturated or completely cutoff nearly all the time. This results in very low power dissipation by the transistor and efficiencies of more 90% which is significantly higher than for linear amplifiers.

E7B02/E7B03 – The switching action creates an output waveform that is a series of squared-off pulses very rich in harmonics. A low-pass filter at the amplifier output removes the harmonics while leaving signals in the desired range of frequencies unmodified.

6-12 – **Distortion and Intermodulation**

The severity of intermodulation distortion depends on the ***order*** of the products that are created, ***even*** or ***odd***.

Even-order products result in spurious signals near **harmonics of the input signal**, and ***odd-order products*** result in spurious signals near the **frequencies of the input signals**.

E7B16 – In a linear power amplifier, the effects of intermodulation will be ***transmission of spurious signals***.

E7B17 – Odd-order intermodulation distortion products are of concern in power amplifiers because they are relatively close in frequency to the desired signal.

Instability and Parasitic Oscillation

6-12/6-13

E7B05 – Preventing unwanted oscillations in and RF power amplifier can be accomplished by ***installing parasitic suppressors and/or neutralizing the stage.***

E7B08 – In order to overcome the positive feedback it is necessary to provide an alternative path from output to input that will supply a voltage that is equal to that voltage causing the oscillation, but with opposite phase (negative feedback).

6-14 – **Signal Processing**

Oscillator Circuits and Characteristics

6-15 – **RF Oscillators**

E7H04 If the reactive divider is a pair of capacitors, it's a ***Colpitts Oscillator*.**

E7H03 – If the reactive divider is a pair of inductors, or more frequently, a single tapped inductor, the circuit is a ***Hartley Oscillator*.**

E7H01 – If the inductor of the Colpitts oscillator is replaced with a quartz crystal, the result is a ***Pierce Crystal Oscillator***, the most stable of the three major oscillator circuits.

E7H05 – The Pierce circuit controls the frequency of the positive feedback through its use of a quartz crystal.

E7H13 – Other sources of high-accuracy frequencies are rubidium oscillators and temperature-stabilized high-Q dielectric resonators such as those found in the laboratory test equipment.

6-15 – **Variable-Frequency Oscillators (VFO)**

E7H06 – Both the Hartley and Colpitts can be used as VFOs.

6-16 – **It's Clear as Crystal**

E6D03 – A piezoelectric material has the ability to change mechanical energy (such as pressure or deformation) into electrical potential (voltage) or ***vice-versa***. This property is known as the piezoelectric effect.

E6D02 – The equivalent circuit of a quartz crystal is motional capacitance, motional inductance, and loss resistance in series, all in parallel with a shunt capacitor representing electrode and stray capacitance.

E7H12 – The crystal manufacturer will specify what capacitance must be place in parallel with the crystal in order for it to resonate at the intended frequency.

6-17 – **Microphonics and Thermal Drift**

E7H02 – If you tune in the signal from an oscillator and tap on the oscillators enclose, you are likely to hear the frequency change a little bit. This response to mechanical vibration is called ***microphonic response***.

E7H07 – Radio designers take great care to mechanically isolate oscillators from vibration by padding, shock absorbers, and careful component selection and layout.

E7H08 – Oscillator designers take care to minimize the oscillator's sensitivity to changing temperatures. One way is by using components like capacitors with NPO (Negative-Positive Zero) temperature coefficients.

Frequency Synthesis

6-17/6-18 – **Direct Digital Synthesis (DDS)**

E7H09 – A ***direct digital synthesizer*** uses a phase accumulator, lookup table, digital to analog converter and a low-pass anti-alias filter.

E7H10 – The lookup table of a direct digital synthesizer contains the ***amplitude values that represent a sine-wave output***.

6-18

E7H11 – The major spectral impurity components produced by a direct digital synthesizer are spurious signals (spurs) at specific discrete frequencies.

Phase-Locked Loops (PLL)

6-19

E7H14 – A phase-locked loop circuit consists of an electronic servo loop consisting of a phase detector, a low-pass filter, a voltage-controlled oscillator, and a stable reference oscillator.

E7H15 – Along with ***frequency synthesis***, a PLL can also be used to perform both ***FM modulation*** and ***demodulation***.

6-20 – **Mixers**

E7E08 – When two sine-waves are combined in a ***nonlinear circuit*** such as a mixer, the output signal is a complex wave form that has the principal components at the frequencies of the two original signals and two ***product*** signals. The product signals are sine-waves whose frequencies are the sum and difference of the frequencies of the two original signals.

6-20

E7E09 – The RF signal should be amplified only enough to overcome mixer losses. Otherwise, strong signals will overload the mixer circuit. This causes desensitization and the higher order combinations of frequencies will appear as highly undesirable spurious signals or intermodulation distortion (IMD) products at or near the IF frequency interfering with the desired signal.

6-22 – **Modulators**

E7E07 – The modulating voice or data is called the ***baseband signal*** or ***baseband information***. The baseband signal contains all of the frequency components present in the modulating signal.

E7E04 – One way a single-sideband phone signal can be generated is by using a balanced modulator followed by a filter.

6-24 – **Frequency and Phase Modulation**

Direct FM

<u>E7E01</u> – The only way to produce a true F3E emission is with a **<u>reactance modulator acting on an oscillator</u>**.

6-25 – **Indirect FM and Phase Modulation**

<u>E7E02</u> – The function of a reactance modulator is to produce PM signals by using an electrically variable inductance or capacitance.

<u>E7E03</u> – An analog phase modulator functions by varying the tuning of an amplifier tank circuit to produce PM signals.

6-26 **Pre-emphasis and De-emphasis**

<u>E7E05</u> – To reduce hiss and high-frequency noise in the receiver, an audio circuit called a ***<u>per-emphasis network</u>*** is added to a direct FM modulator.

<u>E7E06</u> – De-emphasis is commonly used in FM communications receivers for compatibility with transmitters using phase modulation.

6-26

Detectors

<u>E7E10</u> – The simplest type of detector is the ***<u>diode detector</u>***. It works by rectifying, then filtering the received RF signal

6-27

Product Detectors

<u>E7E11</u> – Product detectors are used for SSB, CW and RTTY reception.

Detecting FM Signals

<u>E7E12</u> – The frequency – discriminator circuit uses a transformer tuned to the receivers IF to detect FM signals.

6-28 – **Digital Signal Processing (DSP) and Software Defined Radio (SDR)**

<u>E8A11</u> – Any type of information can be conveyed using digital waveforms – speech, video or even digital data.

<u>E8A12</u> – Digital signals can be regenerated or copied any number of times without error, containing the same information as the original signal.

6-28 – **Digital Signal Processing**

Sequential Sampling

E8A13 – The process of generating a sequence of numbers that represent periodic measurements of a continuous analog waveform is called sequential sampling.

6-29/6-30

E7F05 – To avoid creating aliases by ***undersampling***, the sampling frequency, f_s must be at least twice the highest frequency component of the signal.

6-30 – **Data Converters**

E8A09 – An 8-bit analog – to – digital (ADC) converter can only produce one of $2^8 = 256$ values.

E8A04 – The ADC's measurement can be improved over time by "dithering", adding small amounts of noise to the input signal. This causes the ADC's average output value to be more precise over time.

E7F11 – Assuming atmospheric or thermal noise are not higher, the resolution of the ADC determines the minimum detectable signal level for an SDR.

E8A10 – The purpose of a low-pass filter in conjunction with a digital-to-analog converter is to remove harmonics from the output caused by the discrete analog levels generated.

6-31 – **Fourier Analysis and Fast Fourier Transform (FFT)**

E7F07 – Fast Fourier transform is the key to translating signals from the time domain to the frequency domain.

Decimation and Interpolation

E7F08 – The process of decimation removes every **n^{th}** sample, reducing the effective sample rate by the same factor.

E7F09 – In order to prevent generating aliases due to the new, lower sample rate, a digital low-pass anti-aliasing filter must be applied before decimation.

E7F16 – Both decimation and interpolation can be applied to create fractional changes in effective sampling rate. For example, to change the rate by a factor of ¾, first interpolation by a factor of 3 is applied, then decimation by a factor of 4.

6-32 – **SDR Hardware**

E7F01 – The ultimate SDR architecture is to transition between the analog and digital domains right at the frequency to be transmitted or received with no mixer converting the frequency of received or transmitted signals. This is called ***direct digital conversion***.

E8A08 – DDC requires the ADC and DAC to operate at very high sample rates – at least twice the bandwidth of the transceiver. This requires a direct conversion or flash conversion ADC.

E7F10 – Regardless of whether the digitization is performed directly on the RF signal or on a down-converted or IF signal, the receive and transmit bandwidths are limited by the sample rate of the ADC and DAC respectively.

DSP Modulation

6-34

E7F17 – The letters I and Q in I/Q Modulation represent In-phase (I) and Quadrature (Q).

6-34 – **I/Q Modulation and Demodulation**

6-35

E7F12 – After filtering, the next step in the DSP block is to apply an FFT to the digitized I and Q signals, changing them to the frequency domain.

E7F03 – With DSP, generating SSB, producing a 90^{o} phase shift over a wide frequency range is easily accomplished using a special combination of filters called the ***Hilbert Transform***.

E7F04 – Combining signals with a quadrature phase relationship is a common method of generating SSB signals using digital signal processing.

Filters and Impedance Matching

Filter Families and Response Types

E7C10 – ***Cavity filters*** use the resonant characteristics of a conducting tube or box to act as a filter and are used in repeated duplexers because of their extremely low loss and sharp tuning characteristics.

Filter Classification

6-36 – **Filter Design**

6-37

E7G02 – A filter response's variations in amplitude and phase can even cause ringing, in which certain signal frequencies or oscillations are sustained beyond the duration of the original signal.

E7C14 – Nonlinear phase response can result in distortion of complex signals such as those used in digital modes.

E7C05 – Chebyshev Filter: The passband has variable amounts of ripple, trading flatness of the passband for a sharper cutoff transition.

E7C06 – Elliptical filters have notches in the stopband are positioned at the specific frequencies to make cutoff as sharp as possible.

<u>E7C07</u> – A notch filter would be used to attenuate an interfering carrier signal while receiving an SSB transmission.

6-37 – **Crystal Filters**

<u>E7C15</u> – A crystal lattice filter has narrow bandwidth and steep response skirts.

6-38

<u>E7C08</u> – The bandwidth and response shape of lattice filters depends on ***<u>the relative frequencies of the individual crystals</u>***.

<u>E7C09</u> – A Jones Filter is used as ***<u>a variable bandwidth crystal lattice filter</u>*** as part of an HF receiver's IF stage.

6-38 – **Active Filters**

<u>OP Amps are often used to build an active filter</u>

6-39 – **Active Audio Filters**

<u>E7G06</u> – The most appropriate use of an op-amp active filter is an audio filter in a receiver.

<u>E7G05</u> – Unwanted ringing and audio instability can be prevented in a multi-section op-amp RC audio filter circuit by restricting both gain and Q.

Digital Signal Processing (DSP) Filters

<u>E7F02</u> – An ***<u>adaptive filter</u>*** can be used for removing unwanted noise from a received SSB signal.

6-40 – **Finite Impulse Response (FIR) Filter**

<u>E7F13</u> – The function of taps in a digital signal processing filter is to ***<u>provide incremental signal delays for filter algorithms</u>***.

<u>E7F14</u> – The higher the number of taps, the more precisely the filter output can be calculated.

6-41 – **Infinite Impulse Response (IIR) Filters**

<u>E7F15</u> – Unlike a symmetrical FIR filter, all frequency components of the input signal are delayed by the same amount.

Impedance Matching

<u>E7C04</u> – The circuit cancels the reactive part of the impedance and then transforms the remaining resistive portion to the desired value.

6-42 – **Pi and Pi-L Networks**

E7C01 – The capacitors and inductors of a low-pass filter Pi-Network are arranged between the network's input and output as, ***a capacitor is connected between the input and ground, another capacitor is connected between the output and ground, and an inductor is connected between the input and output***.

E7B09 – To adjust the pi-network in a power amplifier for the proper operation, the tuning capacitor (C1) is adjusted for minimum plate current, and the loading capacitor (C2) is adjusted for maximum permissible plate current.

6-42/6-43

E7C11 – A filter network which is equivalent to two L-networks connected back-to-back with the inductors in series and the capacitors in shunt at the input and output is commonly called a Pi filter network.

E7C13 – The Pi network's Q can be adjusted by selecting different combinations of component

E7C12 – ***A Pi-network with an additional series inductor on the output*** is used for matching a vacuum tube final amplifier to a 50Ω unbalanced output.

6-43

E7C03 – The Pi-L-network ***provides the greatest harmonic attenuation*** of the three most-used matching networks – The L, Pi, and Pi-L-networks.

T-Networks

E7C02 – A T-network with series capacitors and a parallel shunt inductor has a property of acting as a ***high-pass filter***.

6-44 – **Power Supplies**

Linear Voltage Regulators

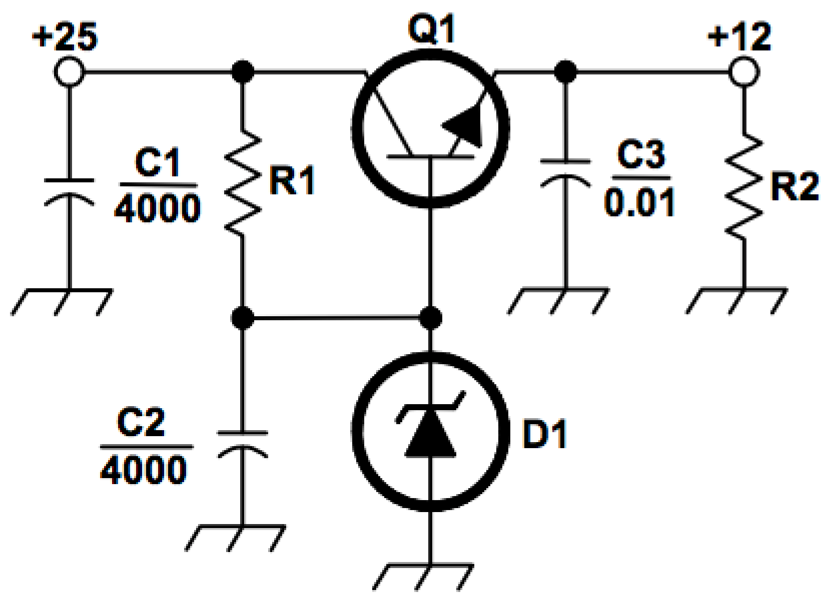
E7D01 – The control element conduction is varied so as to maintain the output voltage at a constant level.

Shunt and Series Regulators

E7D05 – Shunt regulators are most useful when a constant load on the input voltage source results in constant output voltage.

E7D11 – Pass transistors can also be used as the voltage-dropping control element rather than a resistor.

Figure E7- 3



E7D08 – Exam ***Figure E7-3*** shows an example of a ***linear-pass***-transistor ***regulator*** circuit.

E7D03 – The ***voltage reference using a zener diode***, provides the means of comparing output voltage to the desired value or setpoint. ***Figure E7-3***

E7D07 – Capacitor C2 across the zener diode serves to filter hum, ripple and noise from the reference voltage. ***Figure E7-3***

E7D06 – Regulators using pass transistors have much better current handling capabilities due to Q1 than those of simple zener shunt regulators. ***Figure E7-3***

Efficiency and Power Dissipation

E7D13 – $P_{DISS} = (V_{in} – V_{OUT}) \times I_{OUT}$

Power dissipated is equal the difference from input to output voltages multiplied by output current.

6-45/6-46

E7D04 – Because the series regulators control the load directly, they are more efficient than shunt regulators.

6-46

E7D12 – The minimum input-to-output voltage is the regulator's ***drop-out voltage***.

Battery Charging Regulators

E7D09 – If the power source were connected directly to the battery, it might overcharge and damage the battery.

Switching Regulators

E7D02 – The duty cycle of the control element controls the rate at which energy is stored and released and is automatically adjusted to maintain a constant average output voltage.

E7D10 – In an inverter-style power supply, the savings in weight and component cost can be substantial.

High-Voltage Techniques

Capacitors

6-47

E7D16 When several electrolytic filter capacitors are connected in series to increase the operating voltage of a power supply filter circuit, resistors should be connected across each capacitor for the following reasons;

To equalize, as much as possible, the voltage drop across each capacitor.

To provide a safety bleeder to discharge the capacitors when the supply is off.

To provide a minimum load current to reduce voltage excursions at light loads.

E7D15 – In order to reduce stress on the power supply high voltage transformer and rectifier circuits when the supply is turned on, a "step-start" function is often used to charge the filter capacitors gradually.

Bleeder Resistors

E7D14 – A string of bleeder resistors across the filter capacitors improves output voltage regulation of an otherwise unregulated high-voltage supply.

Chapter 7 – Radio Signals and Measurements

7-2 – The amplitude (A) of the sine-wave is equal to the sine of the wheel's angular position in degrees.

Equation 7.1

$A=\text{sine}(\Theta)$

Equation 7.2

$\Theta=360(t/T)$

Where; t = any instant in time

T = period (frequency)

Equation 7.3

$A=\text{sine}[360(t/T)] = \text{sine}[360(1/T) \times t] = \text{sine}(360 \times f \times t)$

7-3 – **Sawtooth Waves**

E8A02 – It has a significantly faster ***rise time*** compared to its ***fall time***.

E8A03 – A fourier analysis will show that a Sawtooth wave is made up of a sinewave at its fundamental frequency and all its harmonics.

7-4 – **AC Measurements**

E8A05 – The RMS value of any waveform, voltage or current can also be determined by measuring the heating effect in a known resistor. ***This is the most accurate method***.

7-5 – **AC Power**

Equation 7.4

$V_{RMS} \times I_{RMS} = P_{AVG}$

Equation 7.5 (For continuous sine waves with voltage and current in phase)

$V_{PEAK} \times I_{PEAK} = P_{PEAK} = 2 \times P_{AVG}$

Power of Modulated RF Signals

7-6 – **Equation 7.7**

$PEP = (PEV \times 0.707)^2/R_{LOAD}$

E8A07 – The characteristics of the modulating signal determines the PEP-to-average power ratio of a single-sideband phone signal.

E8A06 – Typical ratios of PEP to average power are about 2.5:1

7-7 – **Test Equipment**

Multimeters

E4B12 – ***The full scale reading of the voltmeter multiplied by it ohms-per-volt rating will indicate the input impedance of the voltmeter***.

E4B08 – Higher values of sensitivity in Ω/V or of input impedance are generally good for both AC and DC meters.

7-8 – **DIP Meters**

E4B14 – Coupling that is too strong ("tight"), however, almost certainly will change the tuning of the circuit or the dip meter's oscillator, reducing the accuracy of the frequency measurement.

7-9 – **Impedance Bridges**

E4B02 – Bridges are excellent instruments for measuring impedance because obtaining the null of the meter reading can be done precisely.

Frequency Counters and References

7-10

E4A14 – A special type of frequency divider circuit, the ***prescaler*** reduces a signal's frequency by a factor of 10, 100, 1000 or some other integer divisor so that a low-frequency counter can display the input frequency.

E4B01 – Frequency-counter accuracy depends on an internal crystal-controlled reference oscillator, also called the ***time-base***.

E4A15 – An advantage of a ***period-measuring*** frequency counter over a direct-count type is that ***it provides improved resolution of low-frequency signals within a comparable time period***.

Equation 7.8 – **Determining Frequency Counter Error**

Error in Hz = [f(in Hz) x Counter ppm (parts per million)] / 1,000,000

E4B05 – **Example 7.3**

Time base = 10ppm

f = 146.52 MHz

Error(in Hz) = 146,520,000 Hz x 10ppm / 1,000,000

Error(in Hz) = 14,652,000,000/1,000,000 = 1465.20 Hz

E4B04 – **Example 7.4**

Time Base = ±0.1ppm

frequency(f) = 146.52 MHz

Error = 146,520,000 x 0.1/1,000,000 = 14.652Hz

E4B03 – **Example 7.5**

Time Base = ± 1.0ppm

frequency = 146.52 MHz

Error = 146,520,000 x 1ppm/1,000,000 = 146.52Hz

7-11 – **The Oscilloscope**

Oscilloscope Basics

7-12 - **Oscilloscope Probes**

E4A11 – For the most accurate measurements at high frequencies, it is important to keep the ground connection as short as possible.

7-13

E4A13 – The probe is connected to the ***square wave calibration signal*** and its compensation control is adjusted until the square wave's horizontal portions are flat and the corners are sharp.

Digital Oscilloscope

E4A01 – The ***sampling rate*** determines the bandwidth of a digital or computer based oscilloscope.

E4A04 – The upper frequency limit for a computer soundcard-based oscilloscope is determined by the analog-to-digital conversion speed of the soundcard.

E4A09 – The highest frequency signal that can be digitized without aliasing is one-half the sample rate.

7-13

E4A06 – The effect of aliasing in a digital oscilloscope will be the displaying of false, low-frequency signals that the scope will treat just as a real signal.

E4A05 – Advantages of a digital vs. an analog oscilloscope include;

Automatic amplitude and frequency numerical readout.

Storage of traces for future reference.

Manipulation of time base after trace capture.

The Logic Analyzer

E4A10 – A typical logic analyzer has at least 16, and sometimes many more input channels so that all bits can be captured and displayed simultaneously along with auxiliary enable/disable and clock signals.

7-14 **The Spectrum Analyzer**

Time and Frequency Domain

Spectrum Analyzer Basics

7-15

E4A02 – The horizontal axis of the spectrum analyzer displays frequency and the vertical axis analyzer displays signal amplitude.

E4A03 – You can easily see any spurious signals from the transmitter on a spectrum analyzer.

E4A12 – The power attenuator should be able to attenuate the transmitter output power to a safe level for the sensitive spectrum analyzer input, typically 10mW or less.

7-16

E4B10 – To measure intermodulation distortion in an SSB transmitter you would ***modulate the transmitter with two non-harmonically related audio frequencies and observe the RF output with a spectrum analyzer.***

Receiver Performance

Sensitivity and Noise

7-16/7-17 – **Minimum Discernible Frequency (MDS)**

E4C07 – The MDS of a receiver is the strength of the smallest discernible input signal.

E4C05 - -174dBm/Hz represents the ***theoretical noise at the input of a perfect receiver at room temperature.***

7-17

E4C06 – A CW receiver with the AGC off has an equivalent input noise power density of -174dBm/Hz. What would be the level of an unmodulated carrier input to this receiver that would yield an audio output SNR of 0dB in a 400Hz noise bandwidth?

Step 1 – Calculate the bandwidth ratio in dB

dB=10(log)(400) = 26dB

Step 2 – To get MDS, add above figure to -174dBm

MDS = -174dBm + 26dB = ***148dBm***

7-18 – **Noise and Signal-to-Noise Ratio**

E4C04 – ***Noise figure*** is a "figure of merit" for the receiver – it is the ratio in dB of the noise generated by the receiver itself to the theoretical MDS.

E6E05 – A low-noise UHF preamplifier might have a noise figure of 2dB or less.

Equation 7.9

Actual Noise Floor = Theoretical MDS + noise figure

Selectivity

7-19

E4D09 – A ***preselector*** is a tunable input filter adjusted to pass signals at the desired frequency and increase rejection of out-of-band unwanted signals.

E4C02 – Both a ***front-end filter*** or a ***preselector*** improve receiver performance by rejecting signals that can cause image responses in an analog receiver or eliminate overload in an SDR.

E4C13 – A narrow band roofing filter will effect a receiver's performance by ***improving dynamic range by attenuating strong signals near the receive frequency.***

7-20

E4C10/E4C11 – Table 7.2

IF Filter Bandwidth by Signal Type

RTTY or digital	300Hz
SSB	1.5 to 2.7kHz

E4C12 – Wider filters are more comfortable to listen to, but allow undesired signals on nearby frequencies to be heard.

7-20 – **Receiver Dynamic Range**

SDR Dynamic Range

<u>E4C17</u> – ***<u>Sample width</u>*** is the number of bits in each sample of the input signal to the analog-to-digital converter. The larger the number of bits, the larger the range of signals the SDR can process linearly.

<u>E4C16</u> – Distortion can also be created by missing codes.

<u>E4C08</u> – The analog-to-digital converter's maximum input signal level must not be exceeded.

Blocking Dynamic Range

7-21

<u>E4D12/E4D13</u> – Desensitization or desense – the reduction in apparent strength of a desired signal cause by a nearby strong interfering signal.

<u>E4D01</u> – A receiver's blocking level is the power of an input signal that causes 1dB of gain compression.

<u>E4D14</u> – It may be possible to reduce desensitization by using IF filters to reduce the receiver's RF bandwidth and reject the strong signals.

7-22

<u>E4D05</u> – What transmitter frequencies would cause an intermodulation-product signal in a receiver tuned to 146.70MHz when a nearby station transmits on 146.52MHz?

<u>146.34MHz and 146.61MHz</u>

7-23 – **Intercept Points**

<u>E4D10</u> – A 40dBm third-order intercept point means that a pair of 40dBm signals would produce an IMD product of the same 40dBm level.

7-24 – **<u>Equation 7.15</u>**

IMD DR_3 = (2/3)(IP3-MDS)

Where; IMD DR_3 is the 3^{rd} order intermodulation distortion dynamic range in dB

IP3 is the 3^{rd} order input intercept point in dBm

MDS is the noise floor or MDS of the receiver in dB

<u>E4D02</u> – If a receiver has a poor dynamic range, cross-modulation or IMD products will be generated and desensitization (blocking) from strong adjacent signals will occur.

7-25

E4C01 – Excessive phase noise in a receiver local oscillator allows strong signals on nearby frequencies to interfere with the reception of a weak desired signal.

Capture Effect

E4C03 – Capture Effect – The loudest signal received, will be the only signal demodulated, blocking all weaker signals.

7-26

Interference and Noise

Transmitter Intermodulation

E4D08 – IMD (also called cross-modulation) often occurs when signals from several transmitters, each operating on a different frequency, are mixed in a non-linear manner, either by an active electronics device or a passive conductor that happens to have non-linear characteristics.

E4D06 – The ***intermod*** is radiated and received just like the transmitted signal.

E4D07 – It is a clue that an interfering signal is intermod because the modulation from the off-frequency signal is combined with that of the desired signal in the interfering product signal.

7-26/7-27

E4D03 – Intermodulation interference can be produced when two transmitted signals mix in the final amplifiers of one or both transmitters and unwanted signals at the sum and difference of the original signals are generated.

E4D04 – Circulators and isolators effectively reduce intermod problems.

E4E11 – Corroded metal joints are very nonlinear. If two strong AM broadcast stations are nearby, the signals can mix in the joint and generate intermodulation products across a wide range of frequencies, some in the HAM bands.

7-28 – **Atmospheric Static**

E4E06 – The most common source of static noise is caused by the buildup and discharge of static electricity in the atmosphere mostly during thunderstorms.

7-28/7-29

E4E13 – Devices that control voltage or current by opening or closing a circuit can produce momentary arcs that cause interference as pops or clicks. Light dimmers, heater elements and blinking advertising signs are examples. Defective or broken appliances and wiring inside the home can also generate line noise.

E4E05 – One effective way to reduce electrical noise produced by an electric motor is to use a "brute force" AC line filter in series with its power leads.

E6D16 – Connecting a suppressor or snubber capacitor across the low-voltage secondary of a transformer helps absorb the transient's energy instead of allowing it to travel into the power supply.

Locating Noise and Interference Sources

E4E07 – Power down the entire house. Use a battery powered AM receiver and check if you can still hear the noise.

7-30

E4E15/E4E08 – ***Common-mode*** signals picked up on the shields of cables and on unshielded cables such as the AC and telephone wiring may pick up your signals and conduct them to the device or re-radiate the signal and create interference.

E4E16 – Common-mode means that the signal flows in the same direction on all wires in a multiconductor cable such as the power or phone line rather than in opposite directions along the wires as it would on a transmission line.

E4E14 – Computer and network equipment can also generate noise as an unstable modulated or unmodulated signals at specific frequencies.

E4E10 – Touch controlled devices generate noise that sounds like AC hum on an SSB or CW receiver, drift slowly across the band, and can be several kHz wide because the oscillator that generates them is unstable.

Automotive Noise

7-31 – **Vehicular System Noise**

Charging System Noise

7-32

E4E04 – Connect both the positive and negative leads directly to the battery, with proper fuses. Coaxial capacitors in series with the alternator leads may also help.

Noise Reduction

E4E01 – Ignition noise can often be reduced by use of a receiver noise blanker.

E4E03 – The noise blanker must detect signals that appear across a wide bandwidth.

E4E09 – ***Nearby signals may appear to be excessively wide even if they meet emission standards*** when using an IF noise blanker.

E4E02 – DSP filters using adaptive filter techniques work particularly well at removing broadband audio “white” noise. DSP noise reduction also works on impulse noise such as ignition and power line noise.

E4E12 – DSP can sometimes confuse CW and low-rate digital signals and attempt to remove them.

Chapter 8 – Modulation Protocols and Modes

FM/PM Modulation and Modulators

Deviation Ratio

E8B09 – In an FM system, the ratio of the maximum frequency to the highest modulation frequency is called the ***deviation ratio***.

Equation 8.1

Deviation Ratio = D_{MAX}/M

Where; D_{MAX} = peak deviation in Hz

M = Maximum modulating frequency in Hz

8-4 – **Example 8.1**

E8B05 – Peak deviation at 100% is 5kHz and max modulating frequency is 3kHz.

Deviation Ratio = D_{MAX}/M = 5000/3000 = ***1.67***

E8B06 – **Example 8.2**

Max deviation is 7.5kHz and max modulation is 3.5kHz

Deviation Ratio = D_{MAX}/M = 7500/3500 = ***2.14***

8-4 – **Modulation Index**

E8B01 – The ratio of the maximum signal frequency deviation to the instantaneous modulating frequency is called the ***modulation index***.

Equation 8.2

Modulation Index = D_{MAX}/m

Where; D_{MAX} = Peak deviation in Hz

m = modulating frequency in Hz at any given instant

E8B03 – **Example 8.3**

Peak deviation is 3000Hz, modulated by a 1000Hz

Modulation Index = D_{MAX}/m = 3000/1000 = ***3***

8-5

E1B07 – The modulation index allowed below 29.5MHz by FCC rules is 1.0.

Multiplexing

Two common methods of multiplexing, ***Frequency Division Multiplexing (FDM)*** and ***Time Division Multiplexing TDM)***.

E8B10 – FDM uses more than one ***subcarrier***, each modulated by a separate analog signal. The subcarriers are combined into a single ***baseband*** signal and used to modulate the RF carrier.

8-6

E8B11 – TDM is the transmission of two or more signals over a common carrier by interleaving so that the signals occur in different, discrete ***time slots*** of a digital transmission.

Digital Protocols and Modes

Symbol Rate, Data Rate and Bandwidth

E8C02 – ***Symbol rate*** refers to the rate at which the transmitted signal changes in order to convey information.

E8C11 – Baud and symbol rate are the same, so a rate of one baud means that one symbol is transmitted every second.

8-7 – **Protocols and Codes**

E2E12 – ***Automatic control is used by stations using the Automatic Link Enable (ALE) protocol.***

8-8

E2E09 – ***PSK31*** is an ***HF digital mode that uses variable-length coding for bandwidth efficiency***.

ASCII

8-9

E8D11 – ***One advantage of using ASCII code for data communications*** is that ***it is possible to transmit both upper and lower case text***.

E8D12 – ***The advantage of including a parity bit with an ASCII character stream*** is that ***some types of errors can be detected***.

E8D10 – Some of the differences between Baudot digital code and ASCII are;

Baudot uses 5 data bits per character

ASCII uses 7 or 8 bits per character

Baudot uses 2 characters as letters/figure shift codes

ASCII has no letters/figure shift codes

Gray Code

E8C09 – ***Gray Code is the name of a digital code where each preceding or following character changes by only one bit***.

E8C10 – ***Facilitating error detection is an advantage of Gray Code in digital communication where symbols are transmitted as multiple bits***.

8-10 – **Digital Signal Bandwidth**

Equation 8.3

BW = B x K

Where; BW = The necessary bandwidth of the signal

B = The speed of the transmission in baud

K = A factor relating to the shape of the keying envelope

CW

Equation 8.4

BW = (WPM x 0.8) x 5

Where; WPM = words per minute

E8C05 – CW signal is sending 13 words per minute.

BW = (WPM x 0.8) x 5 = (13 x 0.8) x 5 = 10.4 x 5 = 52Hz

8-10/8-11

E8D04 – ***The primary effect of extremely short rise or fall times on a CW signal is the generation of key clicks***.

E8D05 – To ensure your signal is not generating key clicks, increase the rise and fall time.

FSK/DSK

E2E02 – Amateur data transmission (and all those on the HF bands) employ ***frequency shift keying (FSK)***.

E2E11 – ***The difference direct FSK and Audio FSK is that direct FSK applies the data signal to the transmitter VFO***.

Equation 8.5

BW = (K x Shift) + B

Where; BW = necessary bandwidth

K = a constant that depends on the allowable signal distortion and transmission path. For most practical Amateur Radio communication K = 1.2

Shift = The frequency shift in Hz

B = the symbol rate in baud

E8C06 - **Example 8.5**

170Hz shift, 300 baud

BW = (K x Shift) + B

BW = (1.2 x 170Hz) + 300

BW = 504Hz

E8C07 – **Example 8.6**

4800Hz shift, 9600 baud

BW = (K x Shift) + baud

BW = (1.2 x 4800) + 9600 = 15360 Hz = 15.36 kHz

8-12

E2E04 – ***When one of the ellipses in an FSK crossed-ellipse display suddenly disappears, it indicates that selective fading has occurred***.

E8C03 – ***When performing phase shift keying, it is advantageous to shift phase precisely at the zero crossing of the RF carrier*** because ***it results in the least possible transmitted bandwidth for that particular mode***.

E8C04 – ***Use of sinusoidal data pulses is the technique used to minimize the bandwidth requirements of a PSK31 signal.***

8-12

E2E10 – The bandwidth of a PSK31 signal is the narrowest of all HF digital modes used by amateurs.

HF Packet

E2E06 – The most common data rate used for HF packet is 300 baud.

E2D09 – ***300 baud packet*** is the digital mode that has the highest data throughput under clear communication conditions.

Pactor

E2E08 – Pactor protocol also supports the transmission of binary files.

8-13

E2E05 – Winlink can only be used to exchange E-mail and attached files. It does not support keyboard-to-keyboard or chat communications.

Multitone Modes

E2E07 – An MFSK16 signal occupies a bandwidth of 316Hz.

8-13 – **OFDM Modulation**

E8E08 – Orthogonal Frequency Division Multiplexing (OFDM) is described as;

A digital modulation technique using subcarriers at frequencies chosen to avoid intersymbol interference.

WSJT Protocols

E2D01 – FSK441 digital mode was designed for meteor scatter.

E2D03 – JT65 digital mode was designed for EME (Earth-Moon-Earth)

E2D13 – ***JT65 mode*** communications ***uses Multi-tone AFSK***.

E2D12 – JT65 improves EME communications because ***it can decode signals many dB below the noise floor using FEC***.

E2D14 – An advantage of using JT65 coding is ***the ability to decode signals which have a very low signal to noise ratio***.

8-14

E2E03 – JT65 uses 1-minute alternating transmit-receive periods synchronized to accurate timing signals.

Transmitting Digital Mode Signals

E8D06 – ***Strong ALC action*** indicates likely over modulation of an AFSK signal such as PSK or MFSK.

E8D07 – ***Excessive transmit audio levels*** are a common cause of over modulation of AFSK signals.

E8D08 – ***Intermodulation Distortion (IMD)*** might indicate that excessively high input levels are causing distortion in an AFSK signal.

E8D09 – A good minimum IMD level for an idling PSK signal is ***-30dB***.

E2E13 – Possible reasons for failing to contact a digital station on a clear frequency are;

Incorrect transmit frequency

The protocol version you are using is not supported

"Hidden transmitter" is using the frequency

8-15 – **Spread Spectrum Techniques**

E8D01 – Received spread spectrum signals are resistant to interference because ***signals not using the spread spectrum algorithm are suppressed in the receiver***.

8-16 – **Types of Spread Spectrum**

Frequency Hopping

E8D03 – ***Frequency hopping (FH)*** is a form of spreading in which the center frequency of a conventional carrier is altered many times per second in accordance with a pseudo-random list of channels.

Direct Sequence

E8D02 – In direct sequence (DS) spread spectrum, a very fast binary bit stream is used to shift the phase of the modulated carrier.

E2C09 – Ham radio mesh networks are implemented using ***a standard wireless router running custom software***.

8-17 – **Error Detection and Correction**

E8C08 – The simplest form of error correction is ARQ (Automatic Repeat Request). If the receiving station detects an error, it requests a retransmission of the corrupted packet.

E2E02 – When related to digital operation, the letters FEC mean ***Forward Error Correction***.

E8C01 – Forward Error Correction (FEC) is implemented by ***transmitting extra data that may be used to detect and correct transmission errors***.

8-18 – **Amateur Television**

Fast Scan Television

Fast Scan System Components

8-19 – **Image Signal Definitions**

E2B16/E2B02 – For analog TV, U.S. amateurs use the NTSC standard. A total of 525 horizontal scan lines comprise a ***frame*** to form one complete image.

E2B01 – 30 frames are generated each second.

8-20

E2B03 – An interlaced scanning pattern generated in a fast-scan NTSC TV system is generated ***by scanning odd numbered lines in one field and even numbered lines in the next field***.

8-20

E2B04 – Blanking in a video signal refers to ***turning off the scanning beam while it is traveling from right to left or from top to bottom***.

Video Signal Definitions

8-21 – **Composite RGB Video**

E2B07 – The name of the signal component that carries color information in NTSC video is ***Chroma***.

8-22 – **Modulated Television Signals**

RF ATV Signal Characteristics

E2B06 – Most amateurs use ***vestigial sideband (VSB)*** for transmission which is amplitude modulation in which one complete sideband and a portion of the other are transmitted.

E2B05 – VSB uses less bandwidth than a full DSB AM signal but can still be demodulated satisfactorily by simple video detector circuits.

FM Television

E2B18 – Most FM TV equipment operates in the 1.2, 2.4 and 10.25GHz bands.

8-23 – **The Audio Channel**

E2B08 – There are at least 3 ways to transmit voice information with a TV signal;

1) ***Frequency-modulated sub-carrier***
2) ***A separate VHF or UHF audio link***
3) ***Frequency modulation of the video carrier***

Slow Scan Television

8-24 – **Analog SSTV Signal Basics**

E2B12 – Analog SSTV images typically transmitted on the HF bands use ***varying tone frequencies representing the video are transmitted using single sideband***.

E2B15 – ***Specific tone frequencies*** are sent to signal SSTV receiving equipment to begin a new picture line.

E2B14 – ***Tone frequency*** is the aspect of an amateur SSTV signal that encodes the brightness of the picture.

8-25

E2B13 – There are commonly ***128 or 256*** lines used in each frame of an amateur SSTV picture.

E2B17 – ***3kHz*** is the approximate bandwidth of an SSTV signal.

8-25

E2B11 – The purpose/function of Vertical Interval Signaling (VIS) is to ***identify the SSTV mode being used***.

Digital SSTV

E2B09 – Since Digital Radio Mondiale (DRM) signals can be generated and decoded with software on a PC, no additional special equipment beyond a receiver is required to use DRM SSTV communications.

E2B10 – Amateur DRM signals on HF are restricted to normal SSB signal's bandwidth of 3kHz.

8-26

E2B19 – SSTV is permitted in the phone segments of all bands. SSTV signal bandwidth must be no greater than that of a phone signal using the same modulation.

Chapter 9 – Antennas and Feed Lines

Basics of Antennas

Antenna Radiation Patterns

9-2

E9B12 – In the far field, the pattern shape is independent of distance.

Antenna Gain

The Isotropic Radiator

E9A01 – An isotropic radiator is a theoretical, polarized antenna that is assumed to radiate equally in all directions. It serves as a useful theoretical reference for comparison with real antennas.

9-3 – **Directional Antennas**

E9A07 – An antenna's gain is the ratio (expressed in dB) between the signal radiated from an antenna in the direction of its main lobe and the signal radiated from a reference antenna (usually a dipole) in the same direction with the same power.

E9A02 – The isotropic radiator has zero or no gain in any direction.

E9B07 – The gain of directional antennas is the result of concentrating the radio wave in one direction at the expense of radiation in other directions. There is no difference in the total amount of power radiated.

Equation 9.1

Gain in dBd = Gain in dBi – 2.15dB

Where; dBd = antenna gain compared to a reference dipole

dBi = antenna gain compared to an isotropic radiator

9-4 – **Equation 9.2**

Gain in dBi = Gain in dBd = 2.15db

E9A12 – **Example 9.1**

If an antenna has 6dB more gain that an isotropic radiator, how much gain does it have compared to a dipole?

$Gain_{dBd} = Gain_{dBi} - 2.15dB$

$Gain_{dBd} = 6dB - 2.15dB$ ***= 3.85dBd***

E9A13 – **Example 9.2**

If an antenna has 12dB more gain than an isotropic radiator, how much gain does it have compared to a dipole?

$Gain_{dBd} = Gain_{dBi} - 2.15dB$

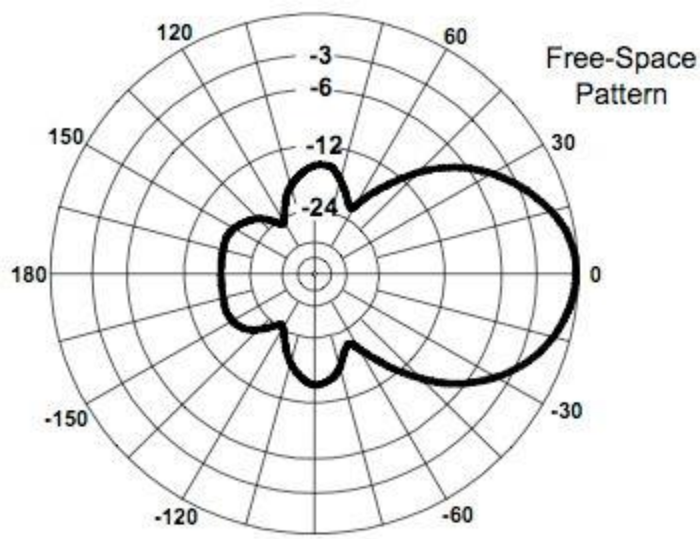
$Gain_{dBd} = 12dBi - 2.15dB =$ ***9.85dBd***

Beamwidth and Pattern Ratio

E9B08 – Beamwidth is the angular distance between the points on either side of the major lobe at which the gain is 3dB below maximum.

E9A06 – As gain is increased, Beamwidth decreases.

Figure E9-1



E9B01 – The main lobe of the pattern crosses the -3dB circle at points 25^o on either side of 0^0. (Figure E9-1) ***So we can estimate the Beamwidth of this antenna as 50^o***

9-5

E9B02 – Find the front-to-back ratio by reading the maximum value of the minor lobe at 180^o. (Figure E9-1) ***18^o***

E9B03 – A front-to-side of ***14dB*** looks like a good estimate for this pattern. (Figure E9-1)

9-6 – **Radiation and Ohmic Resistance**

E9A14 – R is an assumed resistance, that if actually present, would dissipate the power actually radiated by this antenna. This assumed resistance is called ***radiation resistance (R_R)***

E9A05 – The total power dissipated by the antenna is therefore equal to $\mathbf{I^2(R_R+R)}$. These two resistances form the total resistance of the antenna system R_T.

Feed Point Impedance

E9A04 – Feed point impedance can be affected by ***antenna height, conductor length/diameter ratio, and the location of nearby conductive objects***.

9-7 – **Antenna Efficiency**

E9A09 – **Equation 9.3**

Efficiency = R_R/R_T x 100%

Where; R_R = radiation resistance

R_T = total resistance

E9A10 – To be effective, a ¼ wavelength ground-mounted vertical antenna requires a ground system of ***radial wires***, laid out as spokes on a wheel with the antenna element in the center to reduce losses that would otherwise result from current flowing in the lossy soil.

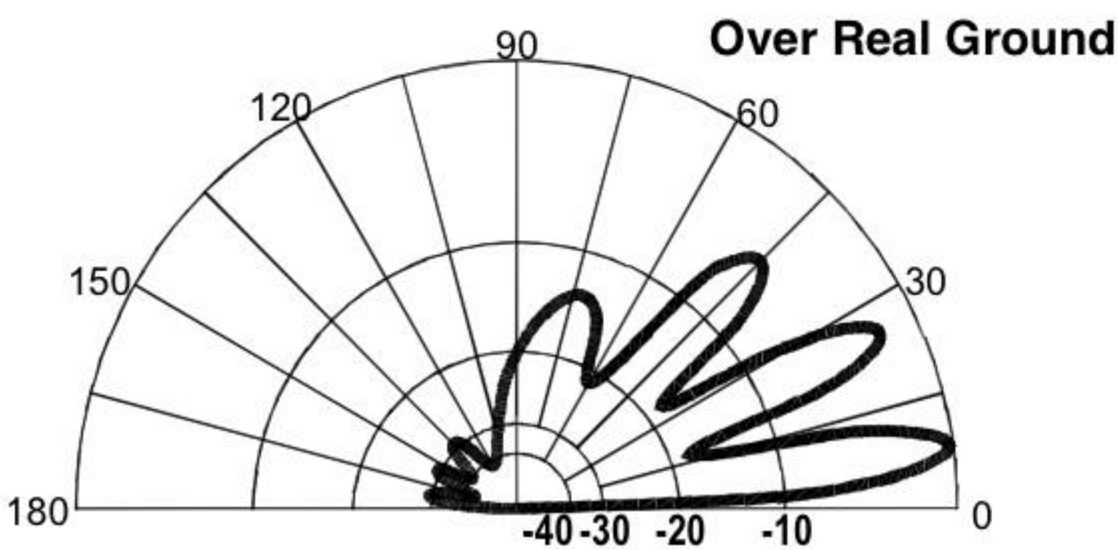
Antenna Polarization

9-8 – **Antenna Pattern Types**

E and H Planes

Azimuthal and Elevation Patterns

Figure E9-2



E9B05 – Figure E9-2 shows a typical elevation pattern with multiple lobes in the forward and backward directions.

E9B16 – Figure E9-2 shows an antenna pattern with 4 forward lobes.

E9B06 – The main forward lobe's take off angle is 7.5°.

Toward the back of the pattern at the takeoff angle, antenna gain is about 28dB below that of the main lobe, so front-to-back ratio for this antenna would be 28dB.

Bandwidth

E9A08 – The bandwidth of an antenna is the frequency range over which it satisfies a performance requirement.

9-9

E9D08 – The higher an antenna's Q, the narrower its SWR bandwidth will be. ***As Q increases, SWR decreases***.

Effects of Ground and Ground Systems

E9A11 – The radiation pattern of an antenna over real ground is always affected by the electrical conductivity and dielectric constant of the soil.

E9C13 – Losses caused by conductivity in the soil near the antenna dramatically reduce signal strength at low angles.

E9C11 – The low-angle radiation from a vertically polarized antenna mounted over sea water will be much stronger than for a similar antenna mounted over rocky soil.

9-9 – **Height Above Ground**

9-10

E9C15 – As the antenna is raised, the takeoff angle of the main lobe decreases.

Terrain

E9C14 – A hilltop is good because reflections from the ground's surface are either reduced or more likely to reinforce the signal at low takeoff angles. For a horizontally polarized antenna, the major lobe's takeoff angle will be lower in the direction of the slope.

Ground Connections

E9D11 – Wide, flat copper straps are the standard for minimizing losses in a station's RF ground system.

E9D12 – An electrically short connection to 3 or 4 interconnected ground rods driven into the Earth provides the best RF ground system for an amateur station.

9-11 – **Practical Antennas**

Dipole Variations

Folded Dipole

E9C08 – A ***folded dipole*** is a wire antenna made from a 1-wavelength long wire that is formed into a very thin loop, 1/2 wavelength long.

9-12

E9C07 – The approximate feed point impedance at the center of a two-wire folded dipole antenna is 300Ω.

Zepp and Extended Double Zepp Antennas

E9C10 – The Zepp is simply a half-wave dipole with an open-wire feed line connected at one end.

E9C12 – An extended double Zepp antenna is, ***a center feed, 1.25 wavelength antenna (two 5/8 wave elements in phase)***.

G5RV

9-13

E9C09 – ***A multi-band dipole antenna fed with coax and a balun through a selected length of open wire transmission line***.

Off-Center Fed Dipole

E9C05 – An OCFD is ***a dipole fed approximately 1/3 the way from one end with a 4:1 balun to provide multiband operation***.

Shortened and Multiband Antennas

Loaded Whip Antennas

9-14

E9D10 – As the operating frequency is lowered, the feed point impedance of such an antenna is a ***decreasing radiation resistance*** in series with an ***increasing capacitive reactance***.

E9D09 – To tune out the capacitive reactance and resonate the antenna, a ***loading coil*** is used.

E9D06 – The trade-off of using loading coils in a shortened antenna is that the SWR bandwidth of the antenna is reduced.

E9D04 – HF loading coils should have a high Q (ratio of reactance to resistance) to minimize losses.

E9D03 – Assuming a high Q, center loading offers the best compromise for minimizing losses in an electrically-short vertical antenna.

9-15

E9D07 – Top loading adds a "capacitive hat" above the loading coil, either just above the coil or near the top of the whip that improves the antenna radiation efficiency.

Trap Antennas

9-16

E9D05 – Trap dipoles and beam antennas have two major disadvantages. Because they are multiband, they will do a good job of radiating any harmonics present in the transmitter.

9-17 – **Traveling Wave Antennas**

E9C04 – The long wire has 4 major lobes (and several minor lobes). The longer the wire, the closer to the direction of the wire the lobes become

Rhombic Antennas

9-18

E9C06 – While the unterminated or resonant rhombic is always bidirectional, the main effect of adding a terminating resistance is to change the radiation pattern to unidirectional by absorbing the power that would have been reflected to create the unwanted second major lobe.

Beverage Antennas

E9H01 – Beverage antennas should be at least one wavelength long at the lowest operating frequency.

9-19

E9H02 – Atmospheric noise is high enough on the lower bands that antenna gain is not important.

Phased Arrays

9-21

E9C03 – ***If two ¼ wavelength vertical antennas are spaced ½ wavelength apart are fed in phase, the radiation pattern will be a figure-8 broadside to the axis of the array***.

E9C01 – ***If two ¼ wavelength vertical antennas are spaced ½ wavelength apart are fed 180^o out of phase, the radiation pattern will be a figure-8 oriented along the axis of the array***.

E9E12 – The primary purpose of a phasing line when used with an antenna having multiple driven elements is to ensure that each driven element operates in concert with the others to create the desired antenna pattern.

E9E13 – A Wilkinson power divider can be used to split the power from the transmitter into equal portions while preventing changes in the loads from affecting power flow to the other loads.

9-21 – **Satellite Antennas**

Gain and Antenna Size

9-22

E9D01 – ***The gain of a parabolic antenna is directly proportional to the square of the frequency.*** That means the gain will increase by 6dB if either the dish diameter or the operating frequency is doubled.

What about Polarization

E9D02 – A circularly polarized antenna can be constructed from two dipoles or Yagis mounted at 90^{o} with respect to each other and fed 90^{o} out of phase.

9-23 – **Receiving Loop Antennas**

E9H09 – A simple receiving loop antenna at MF and HF is a small loop antenna consisting of one or more turns of wire wound in the shape of a large open inductor coil.

9-24

E9H10 – The output voltage of the loop can be increased by increasing the number of turns in the loop or increasing the loop area.

9-24 – **Direction-Finding and DF Antennas**

E9H07 – Some form of RF attenuation is desirable to allow proper operation of the receiver under high signal conditions, such as when zeroing-in on the transmitter at close range. Otherwise the strong signals may overload the receiver.

E9H04 – A shielded loop has the additional advantage of being easier to balance with respect to ground, reducing antenna effect and giving deeper, sharper nulls.

E9H05 – The wire-loop antenna is a simple one to construct, but the bidirectional pattern is a major drawback.

9-25 – **Triangulation**

E9H06 - If two or more RDF (radio direction finding) bearing measurements are made at several locations separated by a significant distance, the bearing lines can be drawn from those positions as represented on a map.

Sense Antennas

E9H08 – A loop may be made to have a single null if a second antenna element, called a sense antenna is added.

E9H11 – The loop and sensing element patterns combine to form a cardioid pattern which has a very sharp, single null.

Terrain Effects

9-26 – **Antenna Systems**

Effective Radiated Power

9-27

E9A18 – Taking into account all station gains and losses is the station's ***effective radiated power***.

Equation 9.4A

ERP = TPO x System Gain

TPO = transmitter power output

Equation 9.4B

ERP = TPO x $\log^{-1}$(System Gain/10)

$\log^{-1} = 10^{(\text{System Gain}/10)}$

Equation 9.4C

ERP (in dBm) = TPO (in dBm) + System Gain (in dB)

9-28

E9A15 – **Example 9.4**

150 watt TPO, 2dB Feed line loss, 2.2dB duplexor loss, 7dBd antenna gain

System Gain = -2dB-2.2dB+7dBd = 2.8dB

ERP = TPO x $\log^{-1}$(System Gain/10)

ERP = 150 watts x $10^{(2.8\text{dB}/10)}$

ERP = 150 watts x $10^{1.9}$ = 150*1.9 = ***285 watts***

E9A16 – **Example 9.5**

200 watt TPO, 4dB feed line loss, 3.2Db duplexor loss, 0.8dB circulator loss, and 10dBd antenna gain.

System Gain = -4db-3.2dB-0.8dB+10dBd = 2dB

ERP = TPO x $\log^{-1}$(System Gain/10)

ERP = 200 watts * $10^{(2dB/10)}$

ERP = 200 watts * $10^{(.5)}$ = 200 watts * 1.58 = ***317 watts***

E9A17 – **Example 9.6**

200 watt TPO, 2dB feed line loss, 2.8dB duplexor loss, 1.2dB circulator loss, 7dBi antenna gain

System Gain = -2dB-2.8dB-1.2dB+7dBi = 1dB

ERP = TPO x $\log^{-1}$(System Gain/10)

ERP = 200 watts * $10^{(1dB/10)}$ = 200 * $10^{.1}$ = 200 * 1.25

ERP = ***252 watts***

9-28 – **Impedance Matching**

9-29

E9A03 – It is important to know the antenna's feed point impedance so a matching system can be designed. When the antenna is matched to the feed line, maximum power transfer to the antenna is achieved and SWR is minimized.

E9E01 – The ***delta match*** gives us a way to match a high-impedance transmission line to a lower impedance antenna. The line connects to the driven element in two places, spaced a fraction of a wavelength on each side of the element center.

The Gamma Match

E9E02 – The gamma match gives us a way to match an unbalanced feed line to an antenna. The feed line attaches to the center of the driven element and at a fraction of a wavelength to one side of center.

9-30

E9E04 – The antenna can be shortened so that its impedance contains capacitive reactance to cancel the inductive reactance of the gamma section, or a capacitance of the proper value can be inserted in series at the input terminals.

9-30

E9E09 – Gamma matches can also be used to match the impedance at the base of a grounded tower to be used as a vertical antenna.

The Hairpin Match

E9E05 – The driven element is tuned so it has a capacitive reactance at the desired operating frequency.

9-31

E9E06 – ***A shunt inductor is the equivalent lumped-constant network for a hairpin matching system of a 3 element Yagi***.

The Stub Match

E9E03 – ***The stub match*** matching system uses a section of transmission line connected in parallel with the feed line at or near the feed point.

E9E11 – The ***universal stub system*** allows a feed line and antenna impedance to be matched, even if both impedances are unknown.

9-31 – **Transmission Lines**

Wavelength in Feed Line

9-32 – **Velocity of Propagation**

E9F02 – The presence of dielectric materials other than air reduces the velocity since electromagnetic waves travel more slowly in materials other than a vacuum.

E9F01/E9F08 – The ratio of the actual velocity at which a signal travels along a line to the speed of light in a vacuum is called the ***velocity factor***.

Equation 9.5

VF = Speed of wave in line/Speed of light in vacuum

Velocity Factor is also related to the dielectric constant represented by Ɛ

Equation 9.6

VF = 1/Square root of Ɛ

E9F02 – Coaxial cable with a solid polyethylene dielectric has a dielectric constant of Ɛ=2.3

VF = 1/Square root of Ɛ

VF = 1/square root of 2.3 = 1/1.5 = 0.66

VF = 0.66

Electrical Length

E9F03 – The electrical length of a transmission line (or antenna) is not the same as its physical length. The electrical length is measured in wavelengths at a given frequency. Waves move slower in the line than in air, so the physical length of the line will always be shorter than the electrical length.

9-33

Equation 9.7

Length (meters) = VF * 300/f (in MHz)

Equation 9.8

Length (feet) = VF * 984/f (in MHz)

Where; f = operating frequency (in MHz)

VF = velocity factor

E9F05 – RG-8 coax that is ¼ wavelength at 14.1MHz. Velocity factor of 0.66

Length (meters) = VF * 300/f (in MHz)

Length (meters) = 0.66 * 300/14.1MHz = 0.66 * 21.28 = 14.1 meters

Divide by 4 to get ¼ wavelength = ***3.52 meters***

9-33

E9F09 – **Example 9.7**

What is the physical length of a coax line that is ¼ wavelength at 7.2MHz with a VF = 0.66

Length (meters) = VF * 300/f (in MHz)

Length (meters) = 0.66 * 300/7.2 = 0.66 * 41.7 = 27.5 meters

Divide by 4 to get ¼ wavelength = ***6.9 meters***

9-34

E9F06 – **Example 9.8**

Physical length of a ½ wavelength at 14.1 MHz VF = 0.95

Length (meters) = VF * 300/f (in MHz)

Length (meters) = 0.95 * 300/14.1 = 0.95 * 21.28 = 20.2 meters

Divide by 2 to get ½ wavelength = ***10.1 meters***

Reflection Coefficient and SWR

E9E07 – The reflection coefficient is a good parameter to describe the interactions at the load end of a mismatched transmission line.

Equation 9.9

$p = Z_L - Z_0 / Z_L + Z_0$

Where; Z_L = Impedance of the load

Z_0 = The line's characteristic impedance

9-35

E9E08 For any impedance mismatch – high-to low or low-to-high – the SWR will be greater than 1:1

Equation 9.10

$SWR = 1+|p|/1-|p|$

Equation 9.11

The reflection coefficient magnitude may be defined as;

$|p| = SWR-1/SWR+1$

Equation 9.12

For $Z_L > Z_0$, $SWR = Z_L/Z_0$

For $Z_L < Z_0$, $SWR = Z_0/Z_L$

9-35 – **Power Measurement**

E4B09 – As a transmitter or antenna tuner get closer to resonance, an increased current reading on an RF ammeter tells you that more power is going to the antenna.

Equation 9.13

p = the square root of P_R/P_F

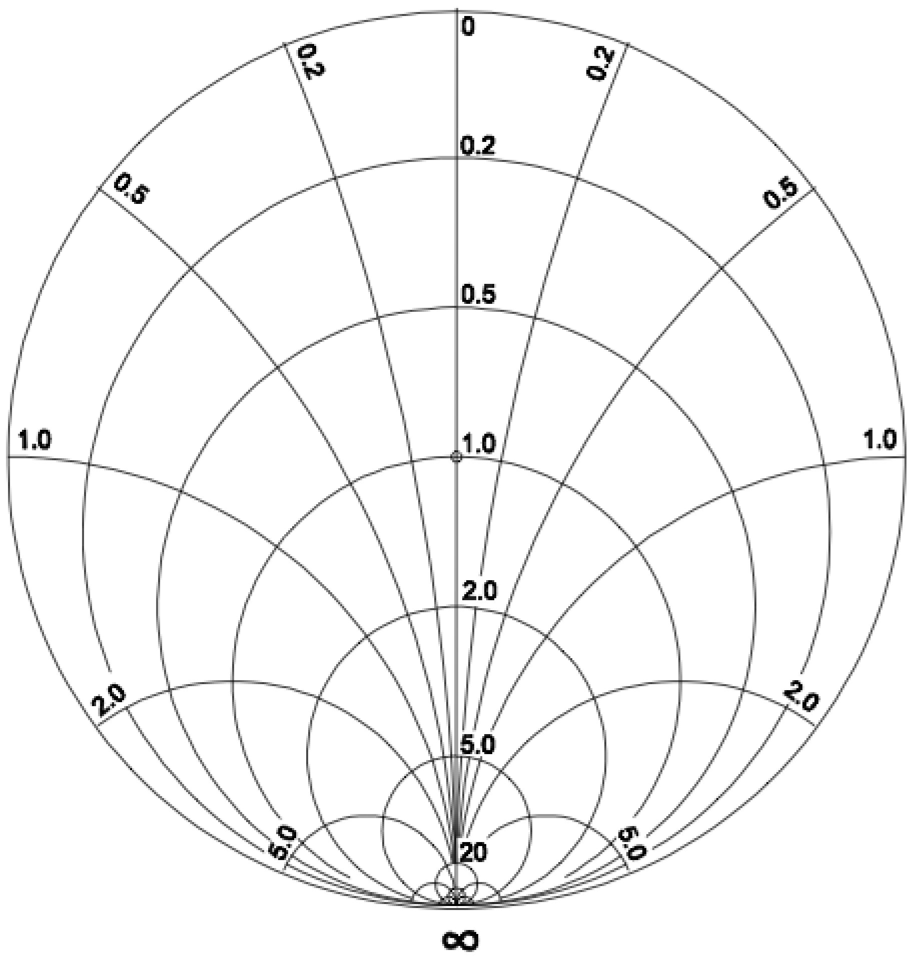
Where; P_R = power in the reflected wave

P_F = power in the forward wave

9-36 - **Smith Chart**

Smith Chart Construction

Figure E9-3



E9G01/E9G03 – The Smith Chart is used, among other things, to calculate impedances and SWR anywhere along a transmission line.

9-37

E9G07 – The only straight line on the chart, the horizontal ***resistance axis*** through the center.

E9G05 – Figure E9-3 is a ***Smith Chart***

9-37

E9G02 – The type of coordinate system used in a Smith Chart is ***Resistance Circles and Reactance Arcs***.

E9G04 – The two families of circles and arcs that make up a Smith Chart are ***resistance and reactance***.

E9G06 – On a Smith Chart the large outer circle on which the reactance arcs terminate is the ***Reactance Axis***.

E9G10 – The arcs on a Smith Chart represent ***points with constant reactance***.

Normalization

E9G08 – Normalization reassigns the impedance values of all points according to their ratio to Z_0 at the prime center, in this case dividing them by 50Ω.

Constant SWR Circles

E9G09 – ***Standing Wave Ratio*** circles are the third family of circles often added to a Smith Chart during the process of solving problems.

9-39 – **Wavelength Scales**

E9G11 – The wavelength scales on a Smith Chart ***are calibrated in fractions of transmission line electrical wavelength***.

Transmission Line Stubs and Transformers

E9F14 – The impedance a ½ wavelength transmission line will present to a generator when the line is ***shorted*** at the far end will be a ***very low impedance***.

E9F15 - The impedance a ½ wavelength transmission line will present to a generator when the line is ***open*** at the far end will be a ***very high impedance***.

E9F13 - The impedance a ¼ wavelength transmission line will present to a generator when the line is ***open*** at the far end will be a ***very low impedance***.

E9F13 - The impedance a ¼ wavelength transmission line will present to a generator when the line is ***shorted*** at the far end will be a ***very high impedance***.

9-40

E9F11 - The impedance a 1/8 wavelength transmission line will present to a generator when the line is ***open*** at the far end will be ***a capacitive reactance***.

Synchronous Transformers

9-41 – **Equation 9.14**

Z_1 = the square root of (Z_0 * Z_{LOAD})

E9E10 – An effective way to match an antenna with a 100Ω feed point impedance to a 50Ω coaxial cable feed line is to ***insert a ¼ wavelength piece of 75Ω coaxial cable transmission line in series between the antenna terminals and the 50Ω feed cable***.

9-42 – **Scattering (S) Parameters**

E4B07 – The subscripts of S parameters represent ***the port or ports at which measurements are taken***.

E4B13 – **S_{21} is the parameter that is equivalent to forward gain.**

Equation 9.15

$RL(dB) = -10\log_{10}(P_{REFL}/P_{INC})$

E4B16 – **S_{11} is the S parameter that represents return loss or SWR**.

Antenna and Network Analyzers

E4A08 – An antenna analyzer would be best for measuring the SWR of a beam antenna.

9-43

E4B11 – The analyzer is used by connecting it directly to the impedance to be measured.

E4A07 – Since the analyzer contains its own low power signal source, it is not necessary to use a transmitter for testing antennas (as you would when an SWR meter is used).

E4B17 – Network analyzers use 3 known loads of 0Ω (short circuit), 50Ω and an open circuit to calibrate themselves.

9-43 – **Antenna Design**

Antenna Modeling and Design

E9B13 – When applied to antenna modeling, the abbreviation NEC means ***Numerical Electromagnetics Code***.

E9B09 – ***Method of Moments*** is a commonly used computer program technique used for modeling antennas.

E9B10 – In the Method of Moments, the antenna wires (or tubing elements) are modeled as a series of ***segments*** and a uniform value of current in each segment is computed.

9-44

E9B11 – A lower number of segments will reduce the time required for model calculations but the outputs, such as pattern shape or feed point impedance will not be as accurate.

Design Tradeoffs and Optimization

E9B04 – You may discover that gain may change rapidly as you move away from its design frequency.

E9D13 – A Yagi antenna optimized for maximum forward gain will usually decrease the front-to-back ratio.

Chapter 10 – Topics in Radio Propagation

Solar Effects

Flux and Flares

10-2

E3C10 – AIA 304 (or 304A) image which shows the Sun at a wavelength of 304 angstroms (30.4nm)

E3C07 – Flares are ranked by intensity: A (small), B, C, M, and X (very large).

E3C09 – An X3 flare is twice as intense as an X2 flare.

10-3

E3C04 – B_2 – a measurement of the intensity and orientation of the interplanetary magnetic field (IMF) generated by the Sun.

E3C05 – If B_2 is negative, the direction of the IMF is aligned southward making it easier for charged particles to enter and disrupt the GMF (Geomagnetic Field)

E3C02 – Increasing values of the A and K indices indicate increasing disruption of the GMF.

E3C08 – G Index – geomagnetic storminess with levels from G0 to G5 (extreme).

HF Propagation

10-4

E3C12 – Ground wave propagation maximum distance decreases as the signal frequency is increased.

E3C13 – Vertically polarized antenna provide the best results for ground wave propagation.

Sky-wave Propagation

E3B12 – The primary characteristic of ***chordal hop*** is successive ionospheric reflections without an intermediate reflection from the ground.

E3B13 – Chordal hop propagation is preferable because the signal experiences less loss.

E3B04 – When radio waves enter the ionosphere they divide into two waves polarized at right angles to each other. The ***ordinary or o-wave*** and the ***extraordinary or x-wave***.

10-5

E3B14 – When a linearly polarized wave splits in the ionosphere it becomes elliptically polarized.

E3C11 – VOACAP is software used to predict HF propagation.

E3C01 – Following the possible paths a wave might take is called ***ray tracing***.

Absorption

10-6

E3C03 – As the A and K indices rise, so does absorption particularly along polar paths.

E3C15 – When a solar flare occurs, noise levels on the HF bands slowly increase as signals fade.

Long-Path and Gray-Line Propagation

E3B07 – If you notice an echo, one signal is coming over short-path and the second is coming over long path.

E3B05 – Long-path propagation can occur on any band with sky-wave propagation (160m to 10m)

E3B06 – Long-path enhancement occurs most often on the 20m band.

10-10

E3A07 – Atmospheric ducts capable of microwave propagation often form over bodies of water.

E3A11 – Ducting can support microwave propagation over 100 – 300 miles.

E3A04 – A map of locations over which tropospheric propagation is likely is called a ***"Hepburn map".***

E3A06 – As long as precipitation is within range of both stations, contacts can be made via ***"rain scatter"***.

Sporadic E Propagation

E3B09 – Most common during the summer solstice and second most common during the winter solstice.

E3B11 – Sporadic E can occur at any time through the day.

Transequatorial Propagation

10-11

E3B03 – The best time is during the afternoon and early evening on HF bands.

E3B02 – TE range extends to approximately 5000 miles – 2500 miles on each side of the magnetic equator.

Auroral Propagation

E3A12 – Caused by charged particles from the Sun interacting with the Earth's magnetic field in the E layer.

10-12

Using Auroral Propagation

E3A13 – CW is the most effective from auroral work.

E3A14 – Stations should point their antennas toward the geomagnetic pole.

10-13

Meteor Scatter Communications

E3A09 – The best range for meteor scatter communications is 28 to 148MHz.

E3A08 – Meteor tails are formed at approximately the altitude of the E layer, 50 to 75 miles above the Earth.

Meteor Showers

10-14 – **Meteor Scatter Techniques**

E2D02 – Techniques for meteor scatter contacts;

1) 15 second timed transmission sequences with stations alternating based on location.
2) Use of high speed CW or digital modes.
3) Short transmissions with rapidly repeated call signs and signal reports.

Earth-Moon-Earth Communications

E3A01 – As long as both stations can "see" the moon, 12,000 miles are possible.

E3A03 – Path loss is lowest when the moon is at perigee – closest to the Earth.

10-14/10-15

E2D06 – A standard calling procedure based on alternating, time synchronized transmissions.

10-15 – **Libration Fading**

E3A02 – Libration fading of EME signals is experienced as fluttery, rapid, irregular fading.

Chapter 11 – Safety

Hazardous Materials

11-1 – **PCBs**

E0A10 – PCBs may be found in older oil-filled high-voltage capacitors and sometimes utility-style high-voltage transformers.

11-2 – **Beryllium and Beryllium Oxide**

E0A09 – Beryllium Oxide (B_3O) dust is toxic if inhaled.

Lead and Soldering

Carbon Monoxide

11-3

E0A07 – The only reliable detection method is a CO detector.

RF Exposure

E0A11 – Exposure to high-power UHF or microwave RF can cause localized heating of the body.

E0A06 – There are separate electric (E) and magnetic (H) field MPE limits because;

1) The body reacts to electromagnetic radiation from E and H fields.
2) Ground reflections and scattering make the field impedance vary with location.
3) E and H field radiation intensity peaks can occur at different locations.

11-4 – **Absorption and Limits**

E0A08 – Specific Absorption Rate (SAR) measures the rate at which RF energy is absorbed by the body.

Averaging and Duty Cycle

11-4 – **Controlled and Uncontrolled Environments**

E0A02 – The homes of your neighbors are uncontrolled environments.

Duty Cycle

11-6 – **Antenna System**

Estimating Exposure and Station Evaluation

E0A03 – The most practical way to estimate whether the RF fields produced are within permissible MPE limits is ***by the use of an antenna modeling program to calculate field strength at accessible locations***.

11-7

E0A04 – ***Each transmitter that produces 5% or more of its MPE limit at accessible locations*** is responsible for mitigating over-exposure situations.

Exposure Safety Measures

11-8

E0A05 – High gain antennas have a narrower beam, but exposure within the beam will be more intense.

Grounding and Bonding

Electrical Safety Ground

11-9 – **Lightning Dissipation Ground**

E0A01 – The primary function of ground rods is making a suitable connection for lightning protection.