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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2016/2017

COURSE NAME	:	ELECTRONIC COMMUNICATION SYSTEM
COURSE CODE	:	BEB 31803
PROGRAMME CODE	:	BEJ / BEV
EXAMINATION DATE	:	DECEMBER 2016 / JANUARY 2017
DURATION	:	3 HOURS
INSTRUCTION	:	SECTION A: ANSWER ALL QUESTIONS SECTION B: ANSWER **THREE (3)** QUESTIONS ONLY

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THIS QUESTION PAPER CONSISTS OF **SIX (16)** PAGES

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SECTION A: ANSWER ALL QUESTIONS (40 MARKS)

Q1 **Figure Q1** shows the result of a bandpass filter in an Amplitude Modulation (AM) receiver. Given that the Intermediate Frequency (IF) is 455 kHz.

(a) Determine the followings:

(i) Q-factor of the filter; and

(2 marks)

(ii) Image Frequency Rejection Ratio (IFRR) in dB.

(4 marks)

(b) Design a tune circuit which will produce the same bandwidth as in **Figure Q1**. The tuned circuit consists of a coil with a 27 Ω resistor connected in parallel with a capacitor.

(4 marks)

Q2 (a) The relationship of Frequency Modulation (FM) and Phase Modulation (PM) are shown in **Figure Q2**. From the **FOUR (4)** graphs (a-d), explain the relationship between FM and PM.

(4 marks)

(b) **Table Q2** shows the specification of commercial FM radio transmission. Given that 25 kHz of guard band is added below and above the carrier frequency swing.

(i) Define frequency deviation.

(1 mark)

(ii) Calculate the carrier swing.

(1 mark)

(iii) Explain the purpose of adding the guard band.

(2 marks)

(iv) Determine the channel bandwidth.

(1 mark)

(v) Calculate the maximum number of stations for the given frequency assignment.

(1 mark)

Q3 (a) A speech signal is sampled at the rate of 8 kHz and then encoded using a uniform quantization. The signal to quantization noise ratio is required to be 40 dB. If the duration of speech is 10 s, calculate the minimum storage capacity needed to accommodate this digitized speech signal.

(4 marks)

(b) Briefly explain **THREE (3)** process involved during analog-to-digital conversion.

(6 marks)

Q4 (a) At high frequency, a transmission line appears as a distributed low-pass filter to any driving generator.

(i) Draw a lumped element model of a distributed line.

(2 marks)

(ii) Produce a simplified equivalent circuit from the lumped element model.

(2 marks)

(iii) Express the relation of the characteristic impedance, Z_o of the line in terms of the lumped components in the simplified equivalent circuit.

(1 mark)

(b) The three basic path that a radio signal can take through space are the ground wave, sky wave and space wave.

(i) Discuss the nature of ground wave that enables the radio signal to be transmitted from the transmitter to the receiver with the help of a simple diagram.

(3 marks)

(ii) Ground wave propagation is insignificant above 3 MHz as the earth begins to attenuate the radio signals. Based on your understanding, explain this limitation of ground wave.

(2 marks)

SECTION B: ANSWER THREE (3) QUESTIONS ONLY (60 MARKS)

Q5 (a) Transmission impairment is any undesired effect on both analog and digital signals while traveling from the transmitter to the receiver. Describe **TWO (2)** causes that contribute to transmission impairment.

(4 marks)

(b) Frequency Division Multiplexing (FDM) and Time Division Multiplexing (TDM) are the multiplexing methods used in telecommunication. Compare the FDM and TDM methods by using suitable diagrams.

(6 marks)

(c) GSM mobile phone operators in Malaysia use 890 – 915 MHz to send information from the Mobile Station (MS) to the Base Station (BS) and 935 – 960 MHz from the BS to MS. There are 124 RF channels with each channel spaced at 200 kHz. Meanwhile, FM radio frequency assignment in Malaysia is between 87.5 MHz and 108.0 MHz. The last FM channel operates from 107.8 MHz to 108.0 MHz. Analyse the thermal noise power of a GSM channel and a FM channel at a temperature of 290 K. Then, conclude your answer.

(5 marks)

(a) A non-ideal amplifier has the following parameters;

Input signal power = 0.2 nW
Input noise power = 0.002 fW
Internal noise power = 6 pW
Power gain = 60 dB

Determine the noise figure.

(5 marks)

Q6 (a) Describe **TWO (2)** advantages of Single Sideband Suppressed Carrier (SSB-SC) over Double Sideband Full Carrier (DSB-FC).

(3 marks)

(b) State **TWO (2)** types of amplitude modulator and give **TWO (2)** examples for each type of modulator.

(3 marks)

(c) **Figure Q6 (c)** shows a diagram of an Amplitude Modulation (AM) transmission. The Function Generator is set with amplitude of 1 V_{p-p} and frequency of 10 kHz, and the Voltage Controlled Oscillator is set with 2 V_{p-p} and frequency of 450 kHz. A Double Sideband Suppressed Carrier (DSB-SC) signal is obtained at point **C** and a Single Sideband Suppressed Carrier (SSB-SC) signal is obtained at point **D**.

(i) Sketch the balance modulator circuit and state its main function.
(3 marks)

(ii) Determine the percentage of the modulation index for DSB-SC.
(1 mark)

(iii) Determine the bandwidth for DSB-SC.
(1 mark)

(iv) Determine the upper and lower sideband voltages and frequencies for DSB-SC.
(3 marks)

(v) Sketch and label completely the DSB-SC signal at point **C** as seen from a spectrum analyser.
(2 marks)

(vi) Name the method used to obtain SSB-SC signal at point **D**.
(1 mark)

(vii) Compare the power transmitted between DSB-SC and SSB-SC if both signals are transmitted through 75 Ω antenna.
(3 marks)

Q7 A frequency modulation (FM) signal has a frequency deviation of 10 kHz and modulated by a sine wave with frequency of 5 kHz. The carrier frequency is 100 MHz and the signal has a total power of 12.5 W operating into an impedance of 50 Ω. Determine:

(a) the modulation index;
(2 marks)

(b) the carrier swing;
(2 marks)

(c) the bandwidth using Bessel Function Table;
(1 mark)

(d) the bandwidth using Carson's rule;
(1 mark)

(e) the sideband frequencies if the modulated signal is filtered by a 20 kHz bandpass filter centered at the carrier frequency;

(2 marks)

(f) the power at the carrier frequency and each of the sideband frequencies found in part **Q7(e)**;

(5 marks)

(g) the percentage of the total unused power for the components described in part **Q7(f)**;

(3 marks)

(h) the full equation for the FM signal; and

(1 mark)

(i) whether this FM signal is a narrowband or wideband signal. Justify your answer.

(3 marks)

Q8 (a) Differentiate between coherent and non-coherent detection in the digital receiver system.

(4 marks)

(b) **Figure Q8** shows a Quadrature Phase Shift Keying (QPSK) modulator.

(i) Determine the output for QPSK modulator.

(5 marks)

(ii) Construct a truth table, constellation diagram, and phasor diagram for QPSK output obtained from **Q8(b)(i)**.

(8 marks)

(iii) Given the input binary sequence 1100100010, sketch the QPSK waveforms.

(3 marks)

Q9 (a) A transmitting antenna has a radiation resistance of 72 Ω, an effective resistance of 8 Ω, a directive gain of 25 and an input power of 100 W. Calculate:

(i) antenna efficiency in percentage;

(2 marks)

(ii) absolute antenna gain; and

(2 marks)

(iii) radiated power in Watt.

(2 marks)

(b) The Ministry of Education Malaysia has awarded a contract to your company to set up a direct line-of-sight communication link between a school in Batu Pahat and the ministry's regional office in Johor Bahru. The line-of-sight distance between the two sites is approximately 150 km. Your plan is to use an antenna with gain of 16 dB for both stations and you have been given the permission by the Malaysian Comission for Communication and Multimedia (MCMC) to operate at frequency of 1.2 GHz. The transmitter produces 10 W of power which is fed to the transmiting antenna via a transmission cable that is 50 meter long with the following characteristics:

Characteristic Impedance = 50 Ω
Attenuation at 1.2 GHz/100m = 10 dB

Solve the followings:

(i) Power at the input of the antenna assuming a matched load in Watt. (4 marks)

(ii) Effective Isotropic Radiated Power (EIRP) of the transmitter in dBW. (2 marks)

(iii) Free space loss in dB. (3 marks)

(iv) Power density at the received antenna. (2 marks)

(v) Power received at the receiving antenna in Watt. Assume no other losses. (3 marks)

- END OF QUESTIONS -

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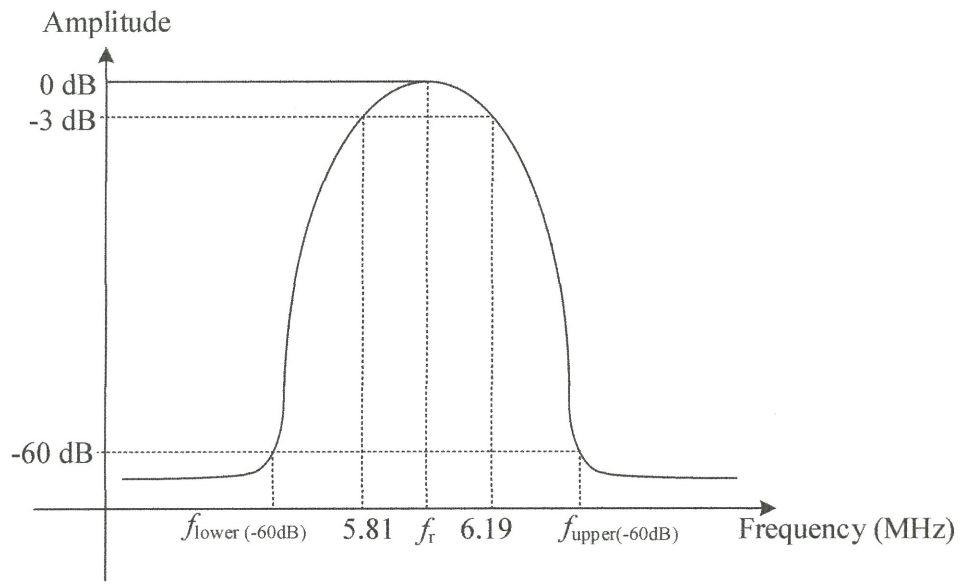

Figure Q1: Frequency response of bandpass filter

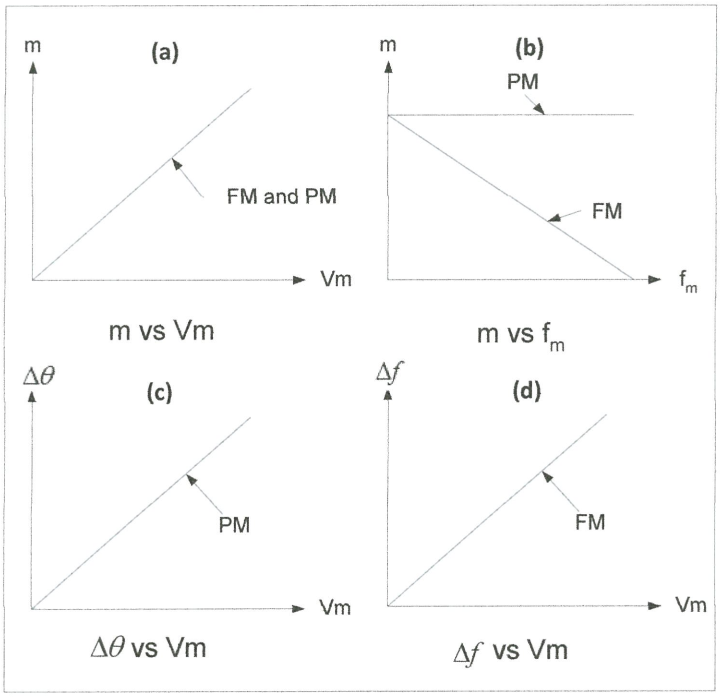

Figure Q2: Relationship of FM and PM

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Table Q2: Commercial FM radio specification

Service Type	Frequency Assignment	Maximum deviation
FM radio broadcast	From 88 MHz to 108 MHz	±75 kHz

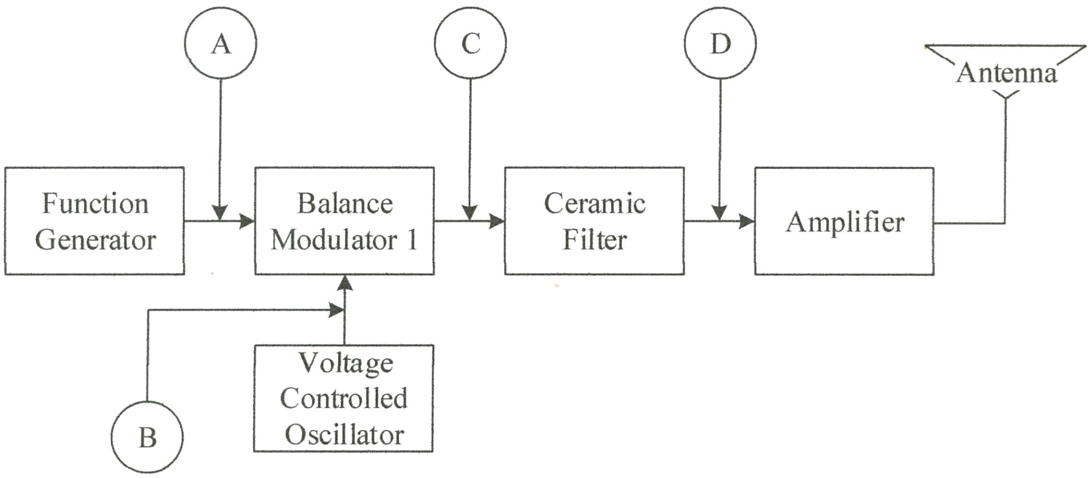

Figure Q6(c): AM Transmitter

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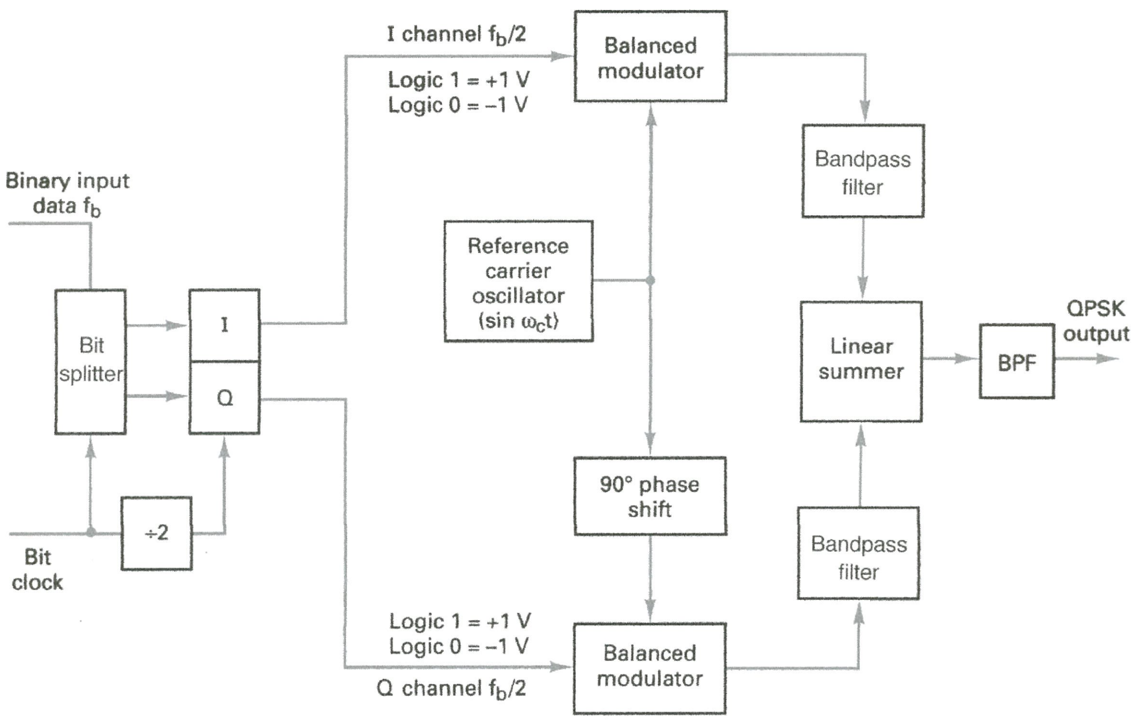

Figure Q8: QPSK Modulator

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Error Function Table

$$\operatorname{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

	Hundredths digit of x									
x	0	1	2	3	4	5	6	7	8	9
0.0	0.00000	0.01128	0.02256	0.03384	0.04511	0.05637	0.06762	0.07886	0.09008	0.10128
0.1	0.11246	0.12362	0.13476	0.14587	0.15695	0.16800	0.17901	0.18999	0.20094	0.21184
0.2	0.22270	0.23352	0.24430	0.25502	0.26570	0.27633	0.28690	0.29742	0.30788	0.31828
0.3	0.32863	0.33891	0.34913	0.35928	0.36936	0.37938	0.38933	0.39921	0.40901	0.41874
0.4	0.42839	0.43797	0.44747	0.45689	0.46623	0.47548	0.48466	0.49375	0.50275	0.51167
0.5	0.52050	0.52924	0.53790	0.54646	0.55494	0.56332	0.57162	0.57982	0.58792	0.59594
0.6	0.60386	0.61168	0.61941	0.62705	0.63459	0.64203	0.64938	0.65663	0.66378	0.67084
0.7	0.67780	0.68467	0.69143	0.69810	0.70468	0.71116	0.71754	0.72382	0.73001	0.73610
0.8	0.74210	0.74800	0.75381	0.75952	0.76514	0.77067	0.77610	0.78144	0.78669	0.79184
0.9	0.79691	0.80188	0.80677	0.81156	0.81627	0.82089	0.82542	0.82987	0.83423	0.83851
1.0	0.84270	0.84681	0.85084	0.85478	0.85865	0.86244	0.86614	0.86977	0.87333	0.87680
1.1	0.88021	0.88353	0.88679	0.88997	0.89308	0.89612	0.89910	0.90200	0.90484	0.90761
1.2	0.91031	0.91296	0.91553	0.91805	0.92051	0.92290	0.92524	0.92751	0.92973	0.93190
1.3	0.93401	0.93606	0.93807	0.94002	0.94191	0.94376	0.94556	0.94731	0.94902	0.95067
1.4	0.95229	0.95385	0.95538	0.95686	0.95830	0.95970	0.96105	0.96237	0.96365	0.96490
1.5	0.96611	0.96728	0.96841	0.96952	0.97059	0.97162	0.97263	0.97360	0.97455	0.97546
1.6	0.97635	0.97721	0.97804	0.97884	0.97962	0.98038	0.98110	0.98181	0.98249	0.98315
1.7	0.98379	0.98441	0.98500	0.98558	0.98613	0.98667	0.98719	0.98769	0.98817	0.98864
1.8	0.98909	0.98952	0.98994	0.99035	0.99074	0.99111	0.99147	0.99182	0.99216	0.99248
1.9	0.99279	0.99309	0.99338	0.99366	0.99392	0.99418	0.99443	0.99466	0.99489	0.99511
2.0	0.99532	0.99552	0.99572	0.99591	0.99609	0.99626	0.99642	0.99658	0.99673	0.99688
2.1	0.99702	0.99715	0.99728	0.99741	0.99753	0.99764	0.99775	0.99785	0.99795	0.99805
2.2	0.99814	0.99822	0.99831	0.99839	0.99846	0.99854	0.99861	0.99867	0.99874	0.99880
2.3	0.99886	0.99891	0.99897	0.99902	0.99906	0.99911	0.99915	0.99920	0.99924	0.99928
2.4	0.99931	0.99935	0.99938	0.99941	0.99944	0.99947	0.99950	0.99952	0.99955	0.99957
2.5	0.99959	0.99961	0.99963	0.99965	0.99967	0.99969	0.99971	0.99972	0.99974	0.99975
2.6	0.99976	0.99978	0.99979	0.99980	0.99981	0.99982	0.99983	0.99984	0.99985	0.99986
2.7	0.99987	0.99987	0.99988	0.99989	0.99989	0.99990	0.99991	0.99991	0.99992	0.99992
2.8	0.99992	0.99993	0.99993	0.99994	0.99994	0.99994	0.99995	0.99995	0.99995	0.99996
2.9	0.99996	0.99996	0.99996	0.99997	0.99997	0.99997	0.99997	0.99997	0.99997	0.99998
3.0	0.99998	0.99998	0.99998	0.99998	0.99998	0.99998	0.99998	0.99999	0.99999	0.99999
3.1	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999
3.2	0.99999	0.99999	0.99999	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

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Complimentary Error Function Table

$$\operatorname{erfc}(x) = 1 - \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

	Hundredths digit of x									
x	0	1	2	3	4	5	6	7	8	9
0.0	1.00000	0.98872	0.97744	0.96616	0.95489	0.94363	0.93238	0.92114	0.90992	0.89872
0.1	0.88754	0.87638	0.86524	0.85413	0.84305	0.83200	0.82099	0.81001	0.79906	0.78816
0.2	0.77730	0.76648	0.75570	0.74498	0.73430	0.72367	0.71310	0.70258	0.69212	0.68172
0.3	0.67137	0.66109	0.65087	0.64072	0.63064	0.62062	0.61067	0.60079	0.59099	0.58126
0.4	0.57161	0.56203	0.55253	0.54311	0.53377	0.52452	0.51534	0.50625	0.49725	0.48833
0.5	0.47950	0.47076	0.46210	0.45354	0.44506	0.43668	0.42838	0.42018	0.41208	0.40406
0.6	0.39614	0.38832	0.38059	0.37295	0.36541	0.35797	0.35062	0.34337	0.33622	0.32916
0.7	0.32220	0.31533	0.30857	0.30190	0.29532	0.28884	0.28246	0.27618	0.26999	0.26390
0.8	0.25790	0.25200	0.24619	0.24048	0.23486	0.22933	0.22390	0.21856	0.21331	0.20816
0.9	0.20309	0.19812	0.19323	0.18844	0.18373	0.17911	0.17458	0.17013	0.16577	0.16149
1.0	0.15730	0.15319	0.14916	0.14522	0.14135	0.13756	0.13386	0.13023	0.12667	0.12320
1.1	0.11979	0.11647	0.11321	0.11003	0.10692	0.10388	0.10090	0.09800	0.09516	0.09239
1.2	0.08969	0.08704	0.08447	0.08195	0.07949	0.07710	0.07476	0.07249	0.07027	0.06810
1.3	0.06599	0.06394	0.06193	0.05998	0.05809	0.05624	0.05444	0.05269	0.05098	0.04933
1.4	0.04771	0.04615	0.04462	0.04314	0.04170	0.04030	0.03895	0.03763	0.03635	0.03510
1.5	0.03389	0.03272	0.03159	0.03048	0.02941	0.02838	0.02737	0.02640	0.02545	0.02454
1.6	0.02365	0.02279	0.02196	0.02116	0.02038	0.01962	0.01890	0.01819	0.01751	0.01685
1.7	0.01621	0.01559	0.01500	0.01442	0.01387	0.01333	0.01281	0.01231	0.01183	0.01136
1.8	0.01091	0.01048	0.01006	0.00965	0.00926	0.00889	0.00853	0.00818	0.00784	0.00752
1.9	0.00721	0.00691	0.00662	0.00634	0.00608	0.00582	0.00557	0.00534	0.00511	0.00489
2.0	0.00468	0.00448	0.00428	0.00409	0.00391	0.00374	0.00358	0.00342	0.00327	0.00312
2.1	0.00298	0.00285	0.00272	0.00259	0.00247	0.00236	0.00225	0.00215	0.00205	0.00195
2.2	0.00186	0.00178	0.00169	0.00161	0.00154	0.00146	0.00139	0.00133	0.00126	0.00120
2.3	0.00114	0.00109	0.00103	0.00098	0.00094	0.00089	0.00085	0.00080	0.00076	0.00072
2.4	0.00069	0.00065	0.00062	0.00059	0.00056	0.00053	0.00050	0.00048	0.00045	0.00043
2.5	0.00041	0.00039	0.00037	0.00035	0.00033	0.00031	0.00029	0.00028	0.00026	0.00025
2.6	0.00024	0.00022	0.00021	0.00020	0.00019	0.00018	0.00017	0.00016	0.00015	0.00014
2.7	0.00013	0.00013	0.00012	0.00011	0.00011	0.00010	0.00009	0.00009	0.00008	0.00008
2.8	0.00008	0.00007	0.00007	0.00006	0.00006	0.00006	0.00005	0.00005	0.00005	0.00004
2.9	0.00004	0.00004	0.00004	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00002
3.0	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00001	0.00001	0.00001
3.1	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
3.2	0.00001	0.00001	0.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

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Bessel Function Table

Modulation index	Carrier J_0	Sidebands									
		J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9	J_{10}
0.0	1.00	—	—	—	—	—	—	—	—	—	—
0.25	0.98	0.12	—	—	—	—	—	—	—	—	—
0.5	0.94	0.24	0.03	—	—	—	—	—	—	—	—
1.0	0.77	0.44	0.11	0.02	—	—	—	—	—	—	—
1.5	0.51	0.56	0.23	0.06	0.01	—	—	—	—	—	—
2.0	0.22	0.58	0.35	0.13	0.03	—	—	—	—	—	—
2.5	−0.05	0.50	0.45	0.22	0.07	0.02	—	—	—	—	—
3.0	−0.26	0.34	0.49	0.31	0.13	0.04	0.01	—	—	—	—
4.0	−0.40	−0.07	0.36	0.43	0.28	0.13	0.05	0.02	—	—	—
5.0	−0.18	−0.33	0.05	0.36	0.39	0.26	0.13	0.06	0.02	—	—
6.0	0.15	−0.28	−0.24	0.11	0.36	0.36	0.25	0.13	0.06	0.02	—
7.0	0.30	0.00	−0.30	−0.17	0.16	0.35	0.34	0.23	0.13	0.06	0.02
8.0	0.17	0.23	−0.11	−0.29	0.10	0.19	0.34	0.32	0.22	0.13	0.06

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Miscellaneous Equations

$sin(A + B) = sinAcosB + cosAsinB$	$sin(A - B) = sinAcosB - cosAsinB$
$cos(A + B) = cosAcosB - sinAsinB$	$cos(A - B) = cosAcosB + sinAsinB$
$sin(2A) = 2\ sinAcosA$	$cos(2A) = cos^2A - sin^2A$
$cos^2A=(1/2)[1+cos2A]$	$sin^2A=(1/2)[1-cos2A]$
$c = 3x10^8\ m/s$	$k = 1.38\ x\ 10^{-23}\ J/K$
$A_v = \frac{V_o}{V_i}$	$A_p = \frac{P_o}{P_i}$
$A_T = A_1 \times A_2 \times A_3 \times \cdots \times A_n$	$\lambda = \frac{c}{f}$
$T = \frac{1}{f}$	$P(dBm) = 10\log\left(\frac{P}{1\times10^{-3}}\right)$
$SNR(dB) = 10\log\left(\frac{P_1}{P_2}\right)$	$SNR(dB) = 20\log\left(\frac{V_1}{V_2}\right)$
$F = F_1 + \frac{F_2 - 1}{A_1} + \frac{F_3 - 1}{A_1A_2} + \cdots + \frac{F_n - 1}{A_1A_2\cdots A_{n-1}}$	$T_e = T(F-1)$
$\frac{S_{out}}{N_{out}} = \frac{A_pS_i}{A_pN_i + N_d}$	$v_c(t) = V_c \sin 2\pi f_c t$
$v_m(t) = V_m \sin 2\pi f_m t$	$V_c = \frac{V_{max} + V_{min}}{2}$
$V_m = \frac{V_{max} - V_{min}}{2}$	$M = \frac{V_m}{V_c} \times 100\%$
$V_{AM}(t) = V_c \sin 2\pi f_c t + \frac{V_m}{2}\cos 2\pi(f_c - f_m)t - \frac{V_m}{2}\cos 2\pi(f_c + f_m)t$	$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$
$P_c = \frac{V_c^2}{2R}$	$P_T = P_c\left(1 + \frac{m^2}{2}\right)$
$P_{USB} = P_{LSB} = \frac{V_m^2}{8R} = \frac{m^2V_c^2}{8R} = \frac{m^2}{4}P_c$	$I_T = I_c\left(1 + \frac{m^2}{2}\right)$
$SF = \frac{BW_{(-60dB)}}{BW_{(-3dB)}}$	$Q = \frac{f_r}{BW}$
$BI = \frac{B_{RF}}{B_{IF}}$	$Q = \frac{X_L}{R}$
High Side Injection, $f_{LO} = f_{RF} + f_{IF}$	Low Side Injection, $f_{LO} = f_{RF} - f_{IF}$
$f_{image} = f_{LO} + f_{IF}$	$f_{image} = f_{RF} + 2f_{IF}$
$\alpha = \sqrt{1 + Q^2\rho^2}$ $IR(dB) = 20\log\alpha$	$\rho = \frac{f_{image}}{f_{RF}} - \frac{f_{RF}}{f_{image}}$

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FINAL EXAMINATION

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Miscellaneous Equations

$v(t) = V_c \sin(2\pi f_c t + \theta(t))$	$\theta(t) = k_p v_m(t) \quad rad$
$\theta'(t) = k_f v_m(t) \quad rad/s$	$\theta(t) = \int \theta'(t)dt$
$v_{PM}(t) = V_c \sin[\omega_c t + \theta(t)]$	$v_{FM}(t) = V_c \sin[\omega_c t + \int \theta'(t)dt]$
$\beta_p = k_p V_m \quad radians$	$\beta_f = \dfrac{k_f V_m}{\omega_m} \quad or \quad \dfrac{k_f V_m}{f_m}$
$\Delta f_c = k_f V_m \quad Hz$	$\Delta\theta = k_p V_m \quad rad$
$\%\text{ modulation} = \dfrac{\Delta f_{actual}}{\Delta f_{\max}} \times 100\%$	$BW_{Bessel} = 2\ (n\ x\ f_m) \quad Hz$
$BW_{Carson} = 2\ (\Delta f + f_m) \quad Hz$	$DR = \dfrac{\Delta f_{\max}}{f_{m(\max)}}$
$P_t = P_0 + 2(P_1 + P_2 + P_3 + ... + P_n) \quad Watt$	$P_n = \dfrac{(J_n \times V_c)^2}{2R} \quad Watt$
$Q_e = \lvert Sampled\ value - Quantized\ value \rvert$ $SQR = \dfrac{V}{Q_n}$ $DR = \dfrac{V_{\max}}{V_{\min}} = \dfrac{V_{\max}}{Resolution}$ $DR = 2^n - 1$	$y = y_{\max} \dfrac{\ln[1 + \mu(\frac{\lvert x \rvert}{x_{\max}})]}{\ln(1+\mu)} \operatorname{sgn} x$ $\operatorname{sgn} x = \begin{cases} +1 & x \geq 0 \\ -1 & x < 0 \end{cases}$
$y = \begin{cases} y_{\max} \dfrac{A(\frac{\lvert x \rvert}{x_{\max}})}{1 + \ln A} \operatorname{sgn} x & 0 < \dfrac{\lvert x \rvert}{x_{mac}} \leq \dfrac{1}{A} \\ y_{\max} \dfrac{1 + \ln[A(\frac{\lvert x \rvert}{x_{\max}})]}{1 + \ln A} \operatorname{sgn} x & \dfrac{1}{A} < \dfrac{\lvert x \rvert}{x_{\max}} < 1 \end{cases}$	$\text{Coding efficiency} = \dfrac{\text{minimum number of bits}}{\text{actual number of bits}} \times 100\%$
$E_b = P_R T_b$	$N_o = kT_N$
$C = 2BW \log_2 M$	$BW = (\dfrac{B}{\log_2 M})$
$Baud = \dfrac{c}{k}$	$erfc(z) = 1 - erf(z)$
$P_{be} = \dfrac{1}{2} erfc\sqrt{\dfrac{E_b}{2N_o}}$	$P_{be} = \dfrac{1}{2} e^{\frac{-E_b}{2N_o}}$

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Miscellaneous Equations

$P_R = \left(\dfrac{P_T G_T G_R}{\left(\dfrac{4\pi d}{\lambda} \right)^2} \right) \times \dfrac{1}{L_t L_r} \quad W$	$P_d = \dfrac{EIRP}{4\pi d^2} \quad \dfrac{W}{m^2}$
$\Gamma = \dfrac{VSWR - 1}{VSWR + 1}$	$Z_0 = \sqrt{\dfrac{L}{C}} \quad \Omega$
$Z_{in} = Z_0 \dfrac{Z_L \cos \beta l + jZ_0 \tan \beta l}{Z_0 \cos \beta l + jZ_L \tan \beta l} \quad \Omega$	$\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)} \quad \dfrac{Np}{m} \text{ or } \dfrac{rad}{m}$