CHAPTER 3
Frequency Division Multiplexing

3.1 What is FDM?:

Several users (channels) can share the same communication gear (hardware) by allocating a specific carrier frequency for every user. At the receiver, a selection mechanism must be set up by which the specific channel may be chosen. This feature is called frequency division multiplexing (FDM). The allocation of carrier frequencies has been the subject of international standardization agreements. It should be noted that the available spectrum- though seemingly extensive- is in fact quite limited, noting the ever-growing number of users and applications. The need to "conserve" the spectrum translates into the necessity to make utmost use of the available spectrum, and cut the bandwidth down to the minimum required for a specific application. Our goal is to increase the efficiency of utilization of the spectrum, even sometimes at the expense of the quality of transmission. Some applications can tolerate degradation of quality, e.g., in telephony the bandwidth is usually limited to 4kHz.

Ex.3.1: Show how FDM is used in a 12 MHz coaxial cable system for 4 kHz bandwidth per channel.

Solution:

In coaxial cable systems, each channel is allocated a specific carrier and a fixed 4kHz bandwidth, irrespective of whether the channel is used or not at any specific time. Commercial speech band 0.3kHz- 3.4kHz is applied to the input of each channel.

Carrier frequencies for 12 channel groups range from 60kHz - 108kHz at 4kHz intervals, with a total bandwidth of 48kHz, using single sideband (LSB) transmission with suppressed carrier. For example, for carrier frequency 108kHz, the output frequency band is 104 – 108kHz, and for carrier 92kHz, the band is 88 – 92kHz, and for carrier 64kHz, the band is 60 – 64 kHz (Table 3.1).

The actual bandwidth is 3.1kHz, but room is left for filtering. Each channel can be filtered out by a band pass filter (BPF). The receiver must consist of such a BPF, or a group (bank of) BPFs to select the required channel or channels.

A supergroup consists of 60 channels (5X12), giving a total bandwidth of 240kHz. The group carrier frequencies and output frequency bands are shown in Table 3.2.

Table 3.1 Carrier frequencies for 12 channel groups

Channel carrier	frequency kHz	Output frequency band kHz
1	108	104 -108
2	104	100 -104
3	100	96 -100
4	96	92 - 96
5	92	88 - 92
6	88	84 - 88
7	84	80 - 84
8	80	76 - 80
9	76	72 - 76
10	72	68 - 72
11	68	64 - 68
12	64	60 - 64

Table 3.2 Group carrier frequencies and output frequency bands

Group	Carrier frequency kHz	Output frequency band kHz
1	420	312 - 360
2	468	360 - 408
3	516	408 - 456
4	564	456 - 504
5	612	504 - 552

Table 3.3 Supergroup carrier frequencies and output frequency bands

Supergroup No.	Carrier frequency kHz	Output frequency band kHz
2	---	312 - 552
3	1116	564 - 804
4	1364	812 - 1052
5	1612	1060 - 1300
6	1860	1308 - 1548
7	2108	1556 - 1796
8	2356	1804 - 2044
9	2604	2052 - 2292
10	2852	2300 - 2540
11	3100	2548 - 2788
12	3348	2796 - 3036
13	2596	3044 - 3284
14	3844	3292 - 3532
15	4092	3540 - 3780
16	4340	3788 - 4028

Table 3.4 Major group carrier frequencies and output frequency bands

Major group	Carrier frequency kHz	Output frequency band kHz
1	----	312 - 4028
2	8448	4420 - 8136
3	12336	8308 - 12024

Groups are then coalesced into a supergroup, with each group of bandwidth of 240kHz, serving as a modulating frequency band. Supergroup carrier frequencies and the output frequency bands are shown in Table 3.2.

Thus, the basic major group consists of 15 supergroups, which are equivalent to 900 channels (15 supergroups x 5 groups per supergroup x 12 channel per group). The resultant band of 312kHz 4028kHz is sent to a major translation group. There are 3 major groups (Table 3.4).

Major group 1 is unmodulated, but is combined with the modulated outputs of major groups 2 and 3. The resultant bandwidth is from 312kHz to 12024kHz. This is sent to the terminal equipment, where it is amplified and transmitted along the coaxial cable.

This system has a total capacity of 2700 channels. Each channel has 4 wires (a pair for each direction). Fig 3.1 shows the line graph for the 12 MHz FDM system just described.

3.2 Multiplexing:

The process by which a number of independent signals can be combined into a composite signal is called multiplexing. The opposite process of decomposing a combined signal into its constituent signals is called demultiplexing.

The block diagram of a general FDM signal is shown in Fig 3.2. The necessary carrier frequencies needed to perform these frequency translations are usually obtained from one common carrier supply.

The different carriers used within the overall modulating signal - carried by the main carrier - are called subcarriers. In other words, each channel has its own subcarrier, but all these subcarriers and their modulating sidebands constitute the baseband to be carried by the overall carrier. The LPFs used before the modulators and the BPFs used after the modulators are important in restricting the bandwidth of each channel to preset values. The resulting outputs are combined (multiplexed) to form the common channel.

At the receiving end, a bank of BPFs - with their inputs connected in parallel - is used to separate the constituent message signals.

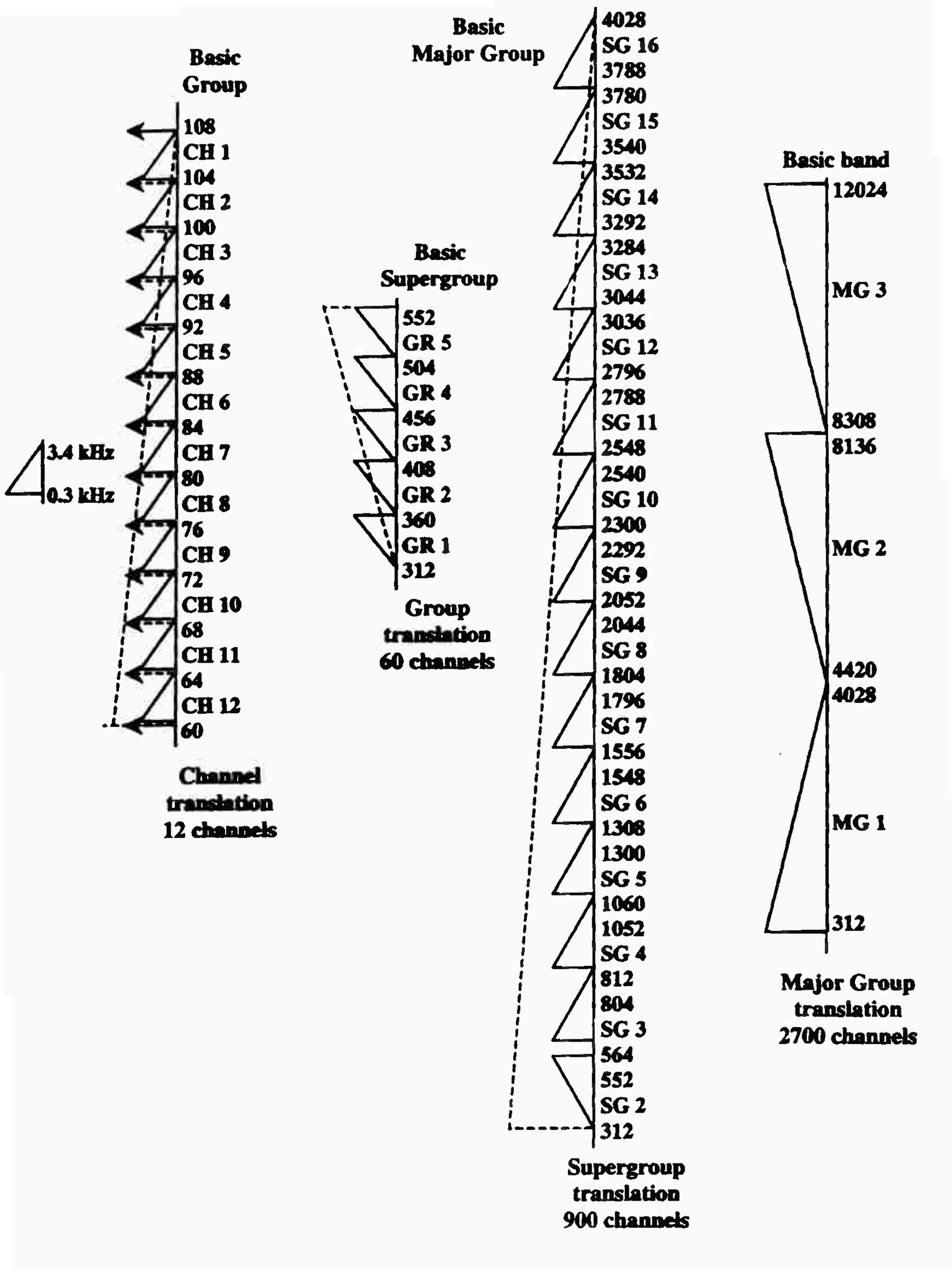

Fig. 3.1 Line graph for a 12MHz coaxial cable system

Each BPF is a tuned circuit with center frequency tuned to mid band value and with bandwidth equal to the bandwidth of the message signal. The original signals are then demodulated by individual demodulators.

Usually, a pilot or reference frequency is required to facilitate demultiplexing and ensure phase synchronism to avoid signal distortion.

3.3 AM Medium Wave Broadcasting Channels:

Another important application of FDM is broadcasting. Here, carriers are assigned for different stations. Together with each carrier, a bandwidth equal to 10kHz allows for double sideband AM (assuming the maximum modulating frequency to be 5KHz). This is not very large, but will serve the purpose for AM broadcasting, where high quality sound is not usually mandatory. This allows for cramming the greatest possible number of stations, especially in the medium wave (MW) band. This extends from 535kHz to 1605kHz. The first carrier is at 540kHz, thus, making room for 106AM channels. It is this range which is usually the most crowded and most utilized.

There is a classification for standard broadcast channels based on the power level. A channel operating at powers up to 50kW providing service for a large area is called " Clear Channel". A "Regional Channel" has power ratings up to 5kW and serves a specific geographical area. A " Local Channel" is 1kW during the day and 250W at night. Such a channel serves a town and its immediate surroundings.

AM broadcasting is usually acceptable for voice information, but is not recommended for music for which another technique is used, which is called frequency modulation (FM) - Chapter 5.

3.4 Short Wave Broadcast Bands:

The transmission of international AM broadcast stations are intended for reception by the public in foreign countries. Such stations have the bands in Table 2.5.

Table 3.5 Short wave broadcast bands

Band	Frequency (MHz)
A	5.95 – 6.2
B	9.5 – 9.755
C	11.7 – 11.975
D	15.1 – 15.45
E	17.7 – 17.9
F	21.45 – 21.75
G	25.6 – 26.1

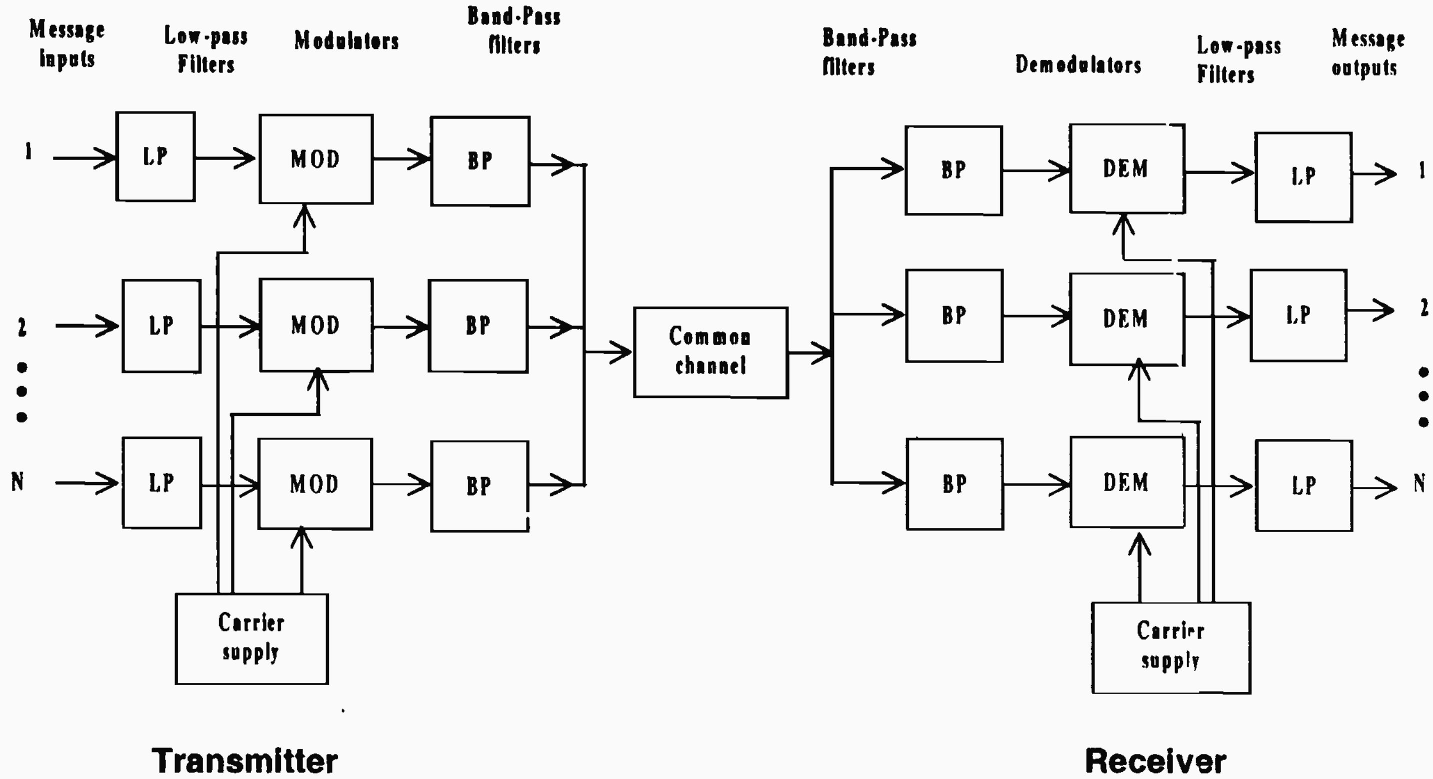

Fig. 3.2 Block diagram of an FDM system

The power level is in excess of 50kW. Radio propagation is such that frequencies below about 500kHz are trapped between the lower ionosphere (about 160km from the surface of the earth) and the surface of the earth, and therefore, propagate chiefly as surface waves.

Frequencies in the range 3 – 30 MHz propagate mostly by reflections and refractions between the earth and the ionosphere as sky waves.

Above 30 – 40 kHz, the energy escapes into space, so that radiation is via space waves. These critical frequencies vary during sunspot cycle and with atmospheric conditions. The effective coverage of short wave transmissions depend on the time of day, time of year and the ionospheric variables that affect the skip or bending of the RF wave.

For this reason, international broadcast stations are assigned more than one frequency in the various short wave bands.

Problems:

1- The practical implementation of an FDM system involves many steps of modulation and demodulation. The first multiplexing step combines 12 voice inputs into a basic group which is formed by having the n[th] input modulate a carrier at $f_c = 60 + 4n$ kHz, where $n =$ 1,2,.. 12

   The lower sidebands are then selected by a BPF. Find the frequency band of the basic group.

2- In the above problem, the 5 basic groups are combined into a supergroup. This is accomplished by using the n[th] group to modulate a carrier $f_c = 372 + 48n$ kHz, where $n =$ 1,2...5. The lower sidebands are selected by filtering. Find the frequency band of the supergroup.

3- Continue the hierarchy of the problem above in forming major groups. Draw a line graph showing the overall system.

4- Calculate the maximum number of AM channels in each of the short wave bands.

5- Calculate the corresponding wavelengths in Medium Wave and Short Wave channels.

6- Sketch the waveform of a DSB signal, SSBSC and DSBSC. Assume 100% modulation. What are the differences?

7- A 400W carrier is modulated at a depth of 80%. Calculate the total power in the modulated wave for DSB, DSBSC and SSBSC.

8- An AM broadcast station has a modulation depth of 75%. What would its average power saving be in going to SSBSC, while having to maintain the same signal strength in the reception area.

9- A signal voltage $V_s = 25\sin 1000t$ and a carrier voltage $V_c = 5\sin 4\times10^6 t$ are applied to the input of a nonlinear resistance whose characteristic is described by the relation: $i = 10 + 2V_i - 0.2V_i^2\ mA$. Determine the amplitude and frequency of all the components of the output current. Calculate the modulation depth.

10- A SSBSC transmitter operating at 16MHz has a frequency stability of 1 part per million. If its transmission is reproduced by a receiver whose frequency stability is 8 parts per million, what is the maximum frequency error that the output receiver would have in reproducing this transmission?

References:

1- "Analogue and Digital Communication Techniques," G. Smillie, Arnold, London, 1999.

2- "Communication systems," 4th ed., S.Haykin, Wiley, N.Y., 2001.

3- "Electronics, Circuits and Applications" W. Burke, D. Irvin, G. Mann, Bobbs Merril, Indianapolis, 1988.

4- "Electronic Communication Systems," 3rd ed., G. Kennedy, Mc Graw Hill, N.Y., 1985.

5- "Electromagnetic Waves and Radiating Systems," E. Jordan and K. Balmain, Prentice Hall, Englewood Cliffs, N.J., 1968.