Communications System Planning

Use of the 220-220 MHz Band For

Highly Efficient and Reliable Communications

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1. INTRODUCTION

This manual is intended to be used as a guide in the system planning and design of 220 to 222 MHz radio systems using the SEA ESP500 and ESP600 series mobiles and the ESP1000 and ESP1100 repeater stations.

Portions of this manual contain information regarding the FCC rules for the 220 - 222 MHz band, DTL® trunking protocol, and recommended antenna system configurations. Because of continuing improvement in our products, be sure to consult the SEA factory or sale representative in your area to keep up to date in the latest factory recommendations.

2. THE 220-222 MHz BAND

2.1 CHANNEL PLAN

The 220-222 MHz band is divided into 400 channels, each 5 kHz wide. The 400 channels are paired to make 200 frequency pairs, with a 1 MHz split between the transmit and receive channels. The 200 channel pairs are divided into several categories of use and/or eligible user. For instance, some channels are available for nationwide use for commercial service, while others are available on a local geographic basis. Figure 1 illustrates the bandplan and the various categories of license.

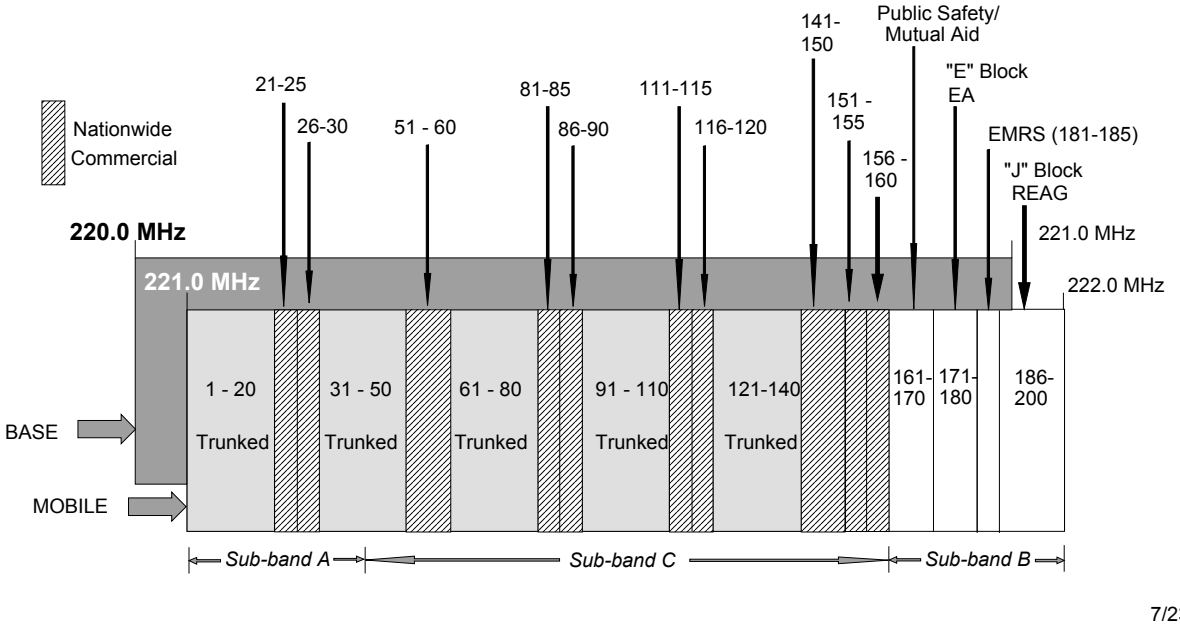


Figure 2.1 220-222 MHz Bandplan

Each channel (pair) is assigned a channel number. Table 1 lists the base station transmit channel

frequencies and channel numbers. The mobile transmit frequency is 1.0 MHz higher than the base frequency.

Table 2.1: 220-222 MHz Band Channel Numbers and Base Station Frequencies

CH #	frequency	CH #	frequency	CH #	frequency	CH #	frequency	CH #	frequency
1	220.0025	41	220.2025	81	220.4025	121	220.6025	161	220.8025
2	220.0075	42	220.2075	82	220.4075	122	220.6075	162	220.8075
3	220.0125	43	220.2125	83	220.4125	123	220.6125	163	220.8125
4	220.0175	44	220.2175	84	220.4175	124	220.6175	164	220.8175
5	220.0225	45	220.2225	85	220.4225	125	220.6225	165	220.8225
6	220.0275	46	220.2275	86	220.4275	126	220.6275	166	220.8275
7	220.0325	47	220.2325	87	220.4325	127	220.6325	167	220.8325
8	220.0375	48	220.2375	88	220.4375	128	220.6375	168	220.8375
9	220.0425	49	220.2425	89	220.4425	129	220.6425	169	220.8425
10	220.0475	50	220.2475	90	220.4475	130	220.6475	170	220.8475
11	220.0525	51	220.2525	91	220.4525	131	220.6525	171	220.8525
12	220.0575	52	220.2575	92	220.4575	132	220.6575	172	220.8575
13	220.0625	53	220.2625	93	220.4625	133	220.6625	173	220.8625
14	220.0675	54	220.2675	94	220.4675	134	220.6675	174	220.8675
15	220.0725	55	220.2725	95	220.4725	135	220.6725	175	220.8725
16	220.0775	56	220.2775	96	220.4775	136	220.6775	176	220.8775
17	220.0825	57	220.2825	97	220.4825	137	220.6825	177	220.8825
18	220.0875	58	220.2875	98	220.4875	138	220.6875	178	220.8875
19	220.0925	59	220.2925	99	220.4925	139	220.6925	179	220.8925
20	220.0975	60	220.2975	100	220.4975	140	220.6975	180	220.8975
21	220.1025	61	220.3025	101	220.5025	141	220.7025	181	220.9025
22	220.1075	62	220.3075	102	220.5075	142	220.7075	182	220.9075
23	220.1125	63	220.3125	103	220.5125	143	220.7125	183	220.9125
24	220.1175	64	220.3175	104	220.5175	144	220.7175	184	220.9175
25	220.1225	65	220.3225	105	220.5225	145	220.7225	185	220.9225
26	220.1275	66	220.3275	106	220.5275	146	220.7275	186	220.9275
27	220.1325	67	220.3325	107	220.5325	147	220.7325	187	220.9325
28	220.1375	68	220.3375	108	220.5375	148	220.7375	188	220.9375
29	220.1425	69	220.3425	109	220.5425	149	220.7425	189	220.9425
30	220.1475	70	220.3475	110	220.5475	150	220.7475	190	220.9475
31	220.1525	71	220.3525	111	220.5525	151	220.7525	191	220.9525
32	220.1575	72	220.3575	112	220.5575	152	220.7575	192	220.9575
33	220.1625	73	220.3625	113	220.5625	153	220.7625	193	220.9625
34	220.1675	74	220.3675	114	220.5675	154	220.7675	194	220.9675
35	220.1725	75	220.3725	115	220.5725	155	220.7725	195	220.9725
36	220.1775	76	220.3775	116	220.5775	156	220.7775	196	220.9775
37	220.1825	77	220.3825	117	220.5825	157	220.7825	197	220.9825
38	220.1875	78	220.3875	118	220.5875	158	220.7875	198	220.9875
39	220.1925	79	220.3925	119	220.5925	159	220.7925	199	220.9925
40	220.1975	80	220.3975	120	220.5975	160	220.7975	200	220.9975

Those channels labeled "trunked" channels in Figure 2.1 are grouped into 5-channel sets as shown in Figure 2.2. There is a 150 kHz separation between each transmit frequency so each group of transmitters may be combined using cavity combining techniques. Table 2.2 shows how the trunked channel groups are organized.

Table 2.2: Trunked Channel Groups

Group No	Channel Nos.
1	1-31-61-91-121
2	2-32-62-92-122
3	3-33-63-93-123
4	4-34-64-94-124
5	5-35-65-95-125
6	6-36-66-96-126
7	7-37-67-97-127
8	8-38-68-98-128
9	9-39-69-99-129
10	10-40-70-100-130
11	11-41-71-101-131
12	12-42-72-102-132
13	13-43-73-103-133
14	14-44-74-104-134
15	15-45-75-105-135
16	16-46-76-106-136
17	17-47-77-107-137
18	18-48-78-108-138
19	19-49-79-109-139
20	20-50-80-110-140

Phase I licenses were granted on a site-by-site basis, with licensees originally granted no more than one 5-channel trunked license within a 40 mile radius. This restriction was eliminated, and many Phase I licenses were consolidated. There were also six nationwide licenses issued in Phase I, and some Public Safety (PSRS) and Emergency Medical (EMRS) channels. Other than the PSRS, EMRS and two of the nationwide licenses (Government), the Phase I licenses were granted by lottery. As of this writing, PSRS and EMRS licenses are still available through the coordination process.

Phase II licenses, gained through competitive bidding, are issued on a geographic basis. Licenses were issued on an EA, REAG or nationwide basis. The United States is divided into 175

economic areas (EAs), and for each EA there are five licenses. Each of these licenses is composed of ten channels; four composed of two trunked groups and one a contiguous block of ten channels. The EA licensees can construct sites anywhere within the respective EA, as long as their base station predicted field strength does not exceed 38dBu[1] outside of the EA.

Regional economic area groupings (REAGs) are groupings of EAs, making much larger geographic regions. There are five REAGs in the US, with five licenses per REAG. Each REAG license is composed of fifteen channels; four are composed of three five-channel trunked groups and one is a contiguous block of fifteen channels. The REAG licensees can construct sites anywhere with the respective REAG, as long as their base station predicted field strength does not exceed 38dBu outside of the REAG. See Table 2.3.

Phase I and II nationwide licensees can construct without geographic restriction. Also, with the advent of Phase II service rules, the "trunking only" requirement was lifted on those channels designated for trunking use during Phase I.

Table 2.3 EA and REAG Assignments

Assignment	Type	Channels or Groups	# of Chs	Phase I use
A	EA	groups 2 & 13	10	local trunked
B	EA	groups 3 & 16	10	local trunked
C	EA	groups 5 & 18	10	local trunked
D	EA	groups 8 & 19	10	local trunked
E	EA	channels 171-180	10	conventional
F	REAG	groups 1, 6 & 11	15	local trunked
G	REAG	groups 4, 9 & 14	15	local trunked
H	REAG	groups 7, 12 & 17	15	local trunked
I	REAG	groups 10, 15 & 20	15	local trunked
J	REAG	channels 186-200	15	data only

Table 2.4 Nationwide Channel Assignments

Channels or Groups	# of Chs	Issued
21 - 25	5	Phase I
26 - 30	5	Phase I
51 - 60	10	Phase II
81 - 90	10	Phase II
111 - 115	5	Phase II
116 - 120	5	Phase I
141-150	10	Phase II
151 - 155	5	Phase I
156 - 160	5	Phase I

[1] The predicted 38 dBu field strength is calculated using the F(50,50) field strength chart for TV Channels 7–13 in § 73.699 (Fig.10) of 47CFR, using a 9 dB correction factor for antenna height differential.

2.2 SERVICE RULES

The FCC has adopted Service Rules for the 220-222 MHz band. These rules cover the technical requirements for approved radio equipment, licensing procedures and conditions of license. This information, for the most part, is contained in Subpart T of Part 90 the FCC Rules.

2.2.1 Technical Equipment Requirements

The following is a summary of the rules regarding the technical requirements for 220 MHz radio equipment.

Table 2.5 Technical Equipment Requirements

PARAMETER	BASE STATIONS	MOBILE STATIONS
Transmitter Power Output	500 Watts ERP max	50 Watts ERP
Transmitter Frequency Tolerance	Within 0.1 ppm (.00001%)	Within 1.5 ppm (.00015%)
Channel Spacing	5 kHz	5 kHz
Authorized Bandwidth	4 kHz	4 kHz

As in other frequency bands, the FCC specifies limitations on transmitter emissions. All emissions from a transmitter that are offset in frequency greater than 3.75 kHz from the center of the transmitter's channel must be attenuated by greater than 55 + 10*log (P) dB from the peak emission power of the transmitter. This means that for a 20 watt PEP transmitter the spurious emissions must be attenuated by greater than 68 dB.

Licensees in control of contiguous channels may aggregate the spectrum and utilize whatever channel bandwidth they desire, but still need to meet the out-of-band emissions attenuation described above at the channel edge.

2.2.2 Geographic Separations and Antenna Heights

Each Phase I system licensed is protected from co-channel interference created by another Phase I system by geographically separating co-channel systems by a minimum of 120 kilometers (75 miles), and by adherence to the base station power output and antenna height limits shown in Table 2.6. Co-channel Phase II systems may be sited anywhere within the EA or REAG that the licensee is authorized for (so long as long as their base station predicted field strength does not exceed 38dBu outside of the EA/REAG). But in order to protect Phase I systems, the 120 km rule still applies. In some circumstances, Phase II sites can be sited closer than 120 km from co-channel Phase I systems. See 47CFR §90.763 for the requirements to do this.

Table 2.6 Base Station Antenna Height and Power Limits

Antenna Height Above Average Terrain (AAT)		Effective Radiated Power (ERP)	
(meters)	(feet)	(Watts)	(dBm)
Up to 150	Up to 492	500	57.0
150 to 225	492 to 738	250	54.0
225 to 300	738 to 984	125	51.0
300 to 450	984 to 1476	60	47.8
450 to 600	1476 to 1969	30	44.8
600 to 750	1969 to 2460	20	43.0
750 to 900	2460 to 2953	15	41.8
900 to 1050	2953 to 3445	10	40.0
Above 1050	Above 3445	5	37.0

The *Sub-bands* referred to in Figure 2.1 are defined for another geographic spacing consideration. Sub-band B base stations are to be separated from Sub-band A base stations by a distance determined by the Sub-band B base transmitter ERP (see FCC rules §90.723 (d)).

3. TRUNKED AND CONVENTIONAL RADIO SYSTEMS

3.1 BASIC TRUNKED DISPATCH OPERATION

Expressed in simple terms, basic trunked mobile dispatch operation is as follows. A more detailed description is given in Section 3.3. Conventional operation is covered in Section 3.6.

When the mobile operator wishes to communicate with another party or others in a given "talk group", the user presses the PTT button on the radio microphone. The radio will then tune to a free channel (typically its "HOME" channel if it is free) and transmit a data message to the repeater tuned to the free channel. The repeater will then send back a data message to the mobile, essentially authorizing the transmission to take place. The data message exchange is called a *handshake*. The initiating mobile's audio becomes active, the operator hears a courtesy beep and may begin talking, and the repeater becomes busy.

The other mobiles to which the transmission is directed will always be tuned to the HOME channel when not in use. The repeater-transmitted half of the handshake will cause the listening mobiles to activate their audio circuits so the transmitting mobile may be heard.

Note: *All data messages are transmitted outside the audio band and are not heard by the mobile users.*

If the calling mobile's HOME repeater is not free, the HOME repeater will be sending periodic data messages to all mobiles that are assigned to it. These data messages inform the mobiles of the repeater number of a FREE repeater in the system. Mobiles that wish to make a call while the HOME repeater is busy are instructed to use the FREE channel. A calling mobile will then transmit on that FREE repeater channel. This causes the repeater controller circuits of the (previously) FREE repeater to inform the calling mobile's HOME repeater of the activity (via the high-speed data bus between trunking controllers). The calling mobile's HOME repeater will send out a data message to the called group to "GO-TO" the repeater channel being used by the calling mobile and enable their audio circuits.

All during the initiating mobile's transmission the repeater is sending data messages instructing the mobiles to stay tuned to that channel. When the initiating mobile operator unkeys, the mobile transmits a *turnoff code*, which is retransmitted by the repeater. The repeater then unkeys itself, and the other mobiles audio circuits are muted. All mobiles involved in the call then tune to their HOME channel for further commands or communication.

In this way, many different, diverse or competing users may effectively use the same set of repeaters in complete privacy and with great channel efficiency.

3.2 DEFINITIONS AND DESCRIPTIONS

Many definitions below are applicable to conventional single repeater operation using DTL data except that the home and traffic channel is always one and the same for conventional operation and no trunking occurs.

3.2.1 Repeater

A repeater (also known as a mobile relay station) is a combination transmitter and receiver with control circuitry. The repeater receives signals transmitted by a mobile or dispatcher control station on one frequency and then re-transmits the audio signal on another frequency where the signal may be received by other mobiles. The repeater makes the decision to re-transmit the signal based on signaling or data recovered by its control circuitry. Repeater antennas are typically installed at high elevations or on tall towers. In this way repeaters are used to extend mobile-to-mobile communications range, which might otherwise be limited by obstacles or terrain. A repeater is said to be a *full duplex* radio because its transmitter and receiver operate at the same time and on different frequencies.

3.2.2 Trunked System

A trunked repeater system is normally a set of repeaters, each operating on a different FCC channel pair, which share the same antenna site. The trunking protocol used in the ESP radio system is the Distributed Trunking Logic scheme (DTL). Each repeater has an associated trunking controller, and all the controllers are linked together by a high-speed trunking control data bus. A mobile operator or dispatcher may select a specific system from the front panel of the transceiver. Logic control programs (in the trunked system controllers) intelligently direct mobile groups to tune to (i.e., trunk off to) other available traffic channels when they wish to communicate while their home channel is busy. The Mode switch on the ESP series mobile allows selection among different trunked systems (subject to the modes programmed into the mobile). See Mode.

3.2.3 Traffic channel

A traffic channel is provided by a repeater capable of relaying voice (or potentially other) information. All repeaters in the system are traffic channels and each typically has at least one mobile group homed to it. Each repeater in a system operates on its own FCC channel pair (1-200) according to the system license. Repeaters transmit on the lower frequency of the channel pair. Mobiles transmit on the upper frequency except during repeater talk-around. Repeater talk-around is normally available only on a conventional mode. See 3.2.11.2 for definition of local and trunked traffic.

3.2.4 Group

A group is a set or fleet of one or more mobiles with a common ID. A mobile operator or dispatcher may (subject to the modes programmed into the transceiver) select a specific group

from the front panel of the transceiver. See Mode and ID codes.

3.2.5 Mode

The ESP504 mobile does not have separate system and group switches. Instead, the mode switch allows selection of up to four systems or any combination of systems/groups totaling four, depending on how the modes are programmed by the dealer. In addition, the ESP504 has available four field test modes (T1-T4) useful only for factory and field test purposes. The ESP520 includes 20 modes, plus field test modes.

3.2.6 Trunking Data Word

Trunking words are data packets sent continuously by active repeaters and transmitting mobiles which pass trunked system control information to the respective mobile and repeater receivers. Trunking words are also known as data messages or data blocks. Each word consists of 40-bits in 7 fields: SYNCH, AREA, GO-TO/IN-USE, HOME, group ID, FREE (or PASS), and checkbits. Section 3.2.11 provides more functional detail.

3.2.7 HOME Channel Field (HOME repeater)

The HOME channel number is the repeater number (1 to 20) that idle mobiles always monitor to wait for instructions. The home channel for a mobile group or fleet is the default traffic channel for that group if it is available when the group needs to communicate. It can also be a traffic channel for a different group if that group's home channel is occupied. In that case, an inactive group which is "homed" to an occupied channel will continue to monitor the home channel to await commands on where to proceed if it requires a traffic channel. All channels in a system can be home channels to some given mobile group. Each mode in the ESP504 allows a single HOME repeater.

Note that the home channel number is not an FCC channel number. Mobiles must be properly programmed to contain information which allows the mobile to automatically convert from the traffic channel numbers (like the home channel) to actual FCC channel numbers and frequencies.

Mobiles always send their home channel number in their word's HOME channel field. Repeaters send the home channel of the mobile group currently being addressed in their word's HOME field.

3.2.8 GO-TO/IN-USE Channel Field and TURNOFF code

The GO-TO field contains the channel number (1-20) sent in repeater words and serves to direct mobile groups to the proper repeater. This channel will often be the same as the home channel. Words transmitted by the mobile contain the channel it is using (1-20) in the same field, in this case called the IN-USE channel. Both mobiles and repeaters transmit the TURNOFF code (31) in this field during the last word sent when terminating transmission.

3.2.9 FREE Channel and PASS

The FREE channel field contains a number from 0-20 sent by repeaters to notify mobiles which repeater is available for new traffic; zero indicating all channels are busy. The FREE channel can be the same as the home channel. A mobile that wishes to initiate communication with its group tunes to this channel before transmitting. Mobiles do not transmit a free channel but instead always transmit 31 (PASS) in this field.

3.2.10 ID Codes

3.2.10.1 **General**

A complete mobile ID code consists of the AREA bit, HOME channel and GROUP ID. It can be thought of as an address or path for signal routing purposes. When discussing a specific home channel in a given system, the ID is understood to be just the group ID (1- 250).

The programmed ID's serve two possible types of operation: dispatch or telephone interconnect. All mobile initiated IDs are retransmitted by the repeater in use (if the system controller considers the ID valid) and also on the home channel repeater if the mobile group is trunked off its HOME channel. Telephone interconnect IDs are typically used by a single mobile to address telephone-line interconnection equipment attached to a repeater. The system operator programs ID types by choosing and assigning different group ID numbers depending on the operation desired.

Section 3.2.12 presents a complete discussion of DTL mobile IDs.

3.2.10.2 **Mobile encode (TX) ID**

A mobile encode ID is that combination of AREA, HOME and encode group IDs transmitted by a mobile when attempting to gain access to a traffic channel. A single TX ID is allowed per mode (with the possible exception of remotely operated radios in a dispatcher's selective calling system). A given encode ID can indicate either of the following:

- the dispatch group/fleet of mobiles that the initiating mobile wishes to communicate with, or

- telephone interconnect request/operation.

The TX ID is selected by the mobile operator or dispatcher by selecting a specific mode (system/group combination).

3.2.10.3 **Mobile decode (RX) IDs**

A mobile decode ID is that combination of AREA, HOME and decode ID programmed into each active mode in the mobile receiver. When this combination is received from the repeater, the receiver's audio output is enabled and some other receiver function may be performed (e.g., call light, horn honk). Each active mode in the ESP504 requires one normal decode ID and may

optionally have two higher-priority IDs, one lower-priority contiguous decode block of IDs and one contiguous block of transmit inhibit IDs. Although it is not required for dispatch operation, the normal decode ID is typically set to the same number as the TX (encode) ID.

3.2.10.4 **Repeater-transmitted ID**

The repeater addressed by the mobile retransmits the ID received from the mobile (plus other information) if the trunked system controller considers that ID to be valid. This results in the following functions:

- connects (performs a two-way handshake) with the initiating mobile to fully enable its transmitter.

- for a dispatch ID: addresses the set of receiving mobiles in the same group or fleet via the home channel repeater and assigns them to the same traffic channel being used by the initiating mobile. Mobiles enable their audio upon reception of the correct ID on the assigned traffic channel.

- for a valid telephone interconnect ID: Causes the telephone interconnection equipment to go off hook which then provides a dial tone back to the initiating mobile.

3.2.11 System Data Messages (DTL trunking data words)

System data messages are digital signaling blocks which are sent by a mobile/dispatcher to request a communications path to other mobiles (mobile-to-repeater) or to instruct mobiles which channel they should be tuned to and to enable mobile audio circuits (repeater-to-mobile). Each DTL data word is approximately 135 milliseconds in duration and contains 40 bits sent at a nominal 300 bps rate.

3.2.11.1 **Mobile-to-repeater trunking data messages**

Single DTL words are transmitted by the mobile unit during the connection process after the unit operator depresses the PTT button. Words are repeated continuously after connection. There is an optionally programmable transpond function, whereby the mobile unit transmits data messages without operator intervention.

Trunking data words originating from the mobile unit include the following fields:

- SYNCHronization bits (9 bits). This field syncs the repeater with the forthcoming data information.

The following fields contain 31 bits known as the data bits:

- AREA bit (1 bit). This bit is either 0 or 1 for all mobiles and repeaters using a given system. Both repeaters and mobiles use it to verify that the mobile is operating with the correct trunked radio system. This provides a means of distinguishing distant radio systems that may

share one or more of the system's frequencies. The area bit is usually programmed to be 0.

➢ Channel IN-USE identification (5 bits). These bits indicate which repeater the mobile is transmitting to, numbering from 1 to 20. After connecting, the mobile will substitute the TURN OFF code (31) in this field in the last word sent after the operator releases the PTT button. The repeater checks the IN-USE field to verify that it matches the repeater's channel number as part of the data validation process. This is the same field used by the repeater to send the GO-TO channel.

➢ HOME channel identification (5 bits). These bits identify the repeater the mobile considers its "home", numbering 1 to 20. Groups of mobiles that communicate with one another are organized such that they share a common HOME repeater. The repeater that receives this information from the mobile, if it is not itself the mobile's HOME channel, notifies the mobile's HOME repeater via the high-speed data bus to report the trunked mobile's activity.

➢ ID code (8 bits). ID codes identify the mobile or group of mobiles targeted to receive a message. The ID codes are used as mobile addresses, numbering 1 to 250. A given mobile will have one TX ID per mode, and an entire mobile group will typically share a single ID. The IDs may be used for different levels of calling (fleet call, group call, individual call), or for the unit to initiate and maintain an interconnect call. The ID codes may be used by the system operator to determine user billing and usage patterns.

➢ FREE (PASS) channel (5 bits). The mobile always sends an invalid code "31" (PASS) in this field because only repeaters may transmit valid free channels.

➢ Checkbits (7 bits). The mobile derives these bits from the five previous fields and appends them as the final bits of the transmitted word. The repeater data receiver also derives checkbits from the previous fields and compares them with the received checkbits to confirm that the data was received without errors. If the checkbits match, further action proceeds. If there is no match, the word is discarded and the repeater waits for reception of the next word.

3.2.11.2 **Repeater-to-mobile trunking data messages**

Any system repeater, for example repeater 1, transmits messages continuously when it has either local or trunked traffic or both. Any mobile group communicating via repeater 1 constitutes local traffic for repeater 1 whether or not that group's home channel is repeater 1. Mobiles homed to repeater 1 but whose groups are trunked to other repeaters cause repeater 1 to send trunked traffic messages.

Repeaters always complete any word that is begun, regardless of changing traffic conditions. They send local words to local traffic mobiles and trunked words to cause homed mobiles - which are part of a trunked group - to tune to the proper repeater. The types of data messages are described below:

1) Repeater idle: When the repeater is not handling any kind of traffic, it sends a single message, using the group ID (255) reserved for the idle condition and places its own number in the GO-

TO, HOME, and FREE fields. This typically occurs once every ten seconds. Otherwise, it remains off the air. This message causes the homed mobiles' FREE channel memory to be updated to equal the HOME channel. The idle message normally serves little useful purpose to mobiles since mobiles can also determine home channel availability by noting the lack of carrier from the home repeater. Idle messages can also reset the mobile range light.

2) Repeater has local traffic only: Upon receipt of a valid ID from a mobile, the repeater transmits at minimum three identical local words containing its own channel in the GO-TO field and the mobile's home and ID in the HOME and ID fields. If another repeater is available a valid free channel is sent in the FREE field. This response provides a handshake to the initiating mobile which allows that mobile to transmit continuously, and instructs receiving mobiles in that group to stay on the channel and unmute their audio circuits.

Mobiles belonging to idle groups that are homed to that repeater continue to monitor the repeater. They save the free channel information so they know which of the other system repeaters to tune to if the operator decides to transmit.

If the repeater receives a turnoff code in the IN-USE field from the mobile, the repeater responds with a turnoff code in the GO-TO field and then goes idle. If it ceases to receive words from the mobile for approximately 2 seconds (e.g., signal fades out), it sends a turnoff code in the GO-TO field, its own number in the FREE field, and then goes idle. The repeater may also send one or more idle words immediately following the turnoff word.

3) Repeater has local and trunked traffic: The repeater gets trunked traffic information from the high-speed data bus by looking for any system repeater data slot containing a home number equal to its number. If the repeater has trunked traffic and new local traffic is received, it first sends three local words to the local traffic and then sends local words at least every third word after that. This keeps the local group on channel and keeps their audio paths open. Trunked words are sent in sequence in between local words. See the next paragraph for information contained in trunked word fields.

4) Repeater sending trunked traffic info only: This situation typically arises if the repeater first had both local and trunked traffic and then local traffic ceases. The repeater gets trunked traffic information from the high-speed data bus by looking for any system repeater data slot containing a home number equal to its number. It continuously transmits trunked words indicating, in the GO-TO field, the traffic channel engaged by the trunked off home group, the ID of the trunked off group and sends its own channel number in the HOME and FREE fields. (Remember that trunked words are sent only to mobiles homed to this repeater.) This provides direction to any listening mobiles which are members of the trunked off group and informs other idle home groups that it is free for local traffic. If there is more than one home group trunked off, the trunked words are sent in sequence repeatedly. When trunked traffic ceases, the repeater returns to the idle condition without use of the turnoff code.

5) Repeater Interconnect is active: If a local interconnect is active, the local words sent are the same as paragraphs 2 or 3 above, except that the IDs used are specific to the interconnected repeater. See further details on repeater interconnect operation in Section 3.5.

6) Repeater sends station identification: If this repeater is used for automatic station identification using means such as Morse code, it will do so typically every thirty minutes but not before local traffic has ceased. During station identification it is unable to handle local traffic and places an alternate free channel (if available) in the FREE field and an invalid ID in the group ID field. The GO-TO and HOME fields contain its number. At the end of transmission it will send a turnoff code in the GO-TO field. Homed mobiles desiring to transmit during station identification will trunk to the free repeater.

Data words originating from a repeater include the following fields:

- SYNCHronization bits (9 bits). Same as mobile. See 3.2.11.1.

- AREA bit (1 bit). Same as mobile. See 3.2.11.1

- GO-TO Channel (5 bits). Assuming the repeater has both local and trunked traffic, the GO- TO field contains its own number (1-20) during local traffic words. This tells local traffic to stay on channel.

The GO-TO field contains the turnoff code (31) in the last word sent to local mobiles when local traffic ceases. This tells local traffic mobiles to shut their audio off and to monitor their home channel. It also causes idle homed mobiles to update their free channel memory to equal the home channel.

The GO-TO field contains the proper traffic channel for the home group (1-20) being addressed (in the HOME and ID fields) when sending trunked words to homed mobiles whose groups are trunked off to another channel. This tells any stray mobiles to go join their group's traffic channel.

Idle mobiles homed to this repeater ignore this field unless it is a turnoff code and stay on channel awaiting instructions.

- HOME field (5 bits). Assuming the repeater has both local and trunked traffic, the repeater echoes the home channel of the local traffic during local traffic words. It places its own number in this field for trunked traffic words since all trunked words are addressed to groups whose home channel is this repeater.

- ID code (8 bits). Assuming the repeater has both local and trunked traffic, the repeater echoes the local traffic mobile's ID (1-250) during local words.

During transmission of trunked words, the group ID(s) of the trunked off traffic is obtained from the high-speed data bus and inserted in this field.

When the repeater is idle it sends the idle ID (255) in this field. The busy ID (253) is used during telephone interconnect setup and knockdown.

➢ FREE channel (5 bits). This is a number from 0 to 20, indicating which repeater is available to accept a call, 0 indicating none are available. All mobiles receiving on this channel monitor this value. Idle mobiles, when keyed, will transmit on this channel.

The repeater will send its own number in this field (which is the mobile's HOME channel number) if it has no local traffic or is sending the turnoff code at the completion of local traffic.

When the repeater has local traffic it must determine the number of an available repeater (before it sends each new word) by checking the high-speed data bus for another repeater capable of accepting new local traffic. The repeater controller is always sequentially reading the repeater slots on the high-speed data bus. The usual way it maintains the free repeater number is by updating the FREE field with the number of the slot it is currently reading if that slot's repeater is free and not updating if that slot's repeater is busy. This causes the free repeater number to change almost on a word-by-word basis in a lightly loaded system.

Additional intelligence in some controllers allows the system operator to choose among options regarding how interconnect-equipped repeaters are made available as free channels for dispatch operation. For example, an interconnected channel can be chosen to be available for dispatch only if it is the last available repeater.

Note that if the mobile is attempting to initiate a telephone call and its HOME interconnected repeater is busy, the free channel presented by the system may or may not be an interconnect-equipped repeater. See section 3.5.2 for further details.

FREE will be zero if the repeater has local traffic and no other repeaters are available. A mobile attempting access while FREE=0 will initiate a busy tone and will not transmit until it receives a valid free repeater.

➢ Check bits (7 bits). Same purpose as for mobile. See 3.2.11.1.

3.2.12 Mobile IDs

This section explains the Mobile DTL IDs and how they are used. The following ID parameters are programmable on a mode-by-mode basis. Optional remote operation for select call consoles, etc., results in variations to the following rules.

1) AREA BIT: This bit must be programmed (0 or 1) to match the area bit of the trunked system repeaters accessed by this mode. If the area bits do not match, neither mobiles nor repeaters can validate received trunking data words.

2) HOME CHANNEL: A number from 1 to 20. The mobile always transmits this value in the HOME field and will receive this value in the HOME field when the repeater responds to it. The mobile will check for a HOME field match during the word validation process.

3) TX (encode) group ID:

The TX ID is a single number from 1-250. The TX ID is sent when the mobile transmits. It is also the ID the repeater will echo back when the repeater addresses the mobile. The transmitting mobile must receive the TX ID back from the repeater to complete a handshake sequence. Receiving mobiles in the same group will have this value as one of their valid RX IDs. Note that, in the ESP504, receipt of a priority RX ID does not affect the TX ID value. Only a mode change (manual or scan) can effect a change in TX ID. A mode designated for receive only can have TX ID = 0.

4) RX (decode) group IDs and options:

Incoming IDs are checked for a possible match with the programmed RX IDs only after the incoming word has been validated. Programming of the NORMAL RX ID in the mobile is mandatory.

Dispatch Operation: RX ID types are listed below in the order that they are checked. The received ID is first compared with the TX INHIBIT block for a match. If a match is found, the TX inhibit timer is set to 5 seconds. It is important to know that the TX inhibit timer is usually cleared to zero if the received ID is later found to match the NORMAL RX ID. ID comparison then continues with the Priority 1 ID, etc., in the order shown. If a match is found for any ID type, the remaining IDs in the list are not checked.

Dispatch Priority Decode: If an incoming ID matches the Priority 2 ID, subsequently received IDs will be checked only for TX inhibit and Priority 1 or Priority 2 ID match. Similarly, if the incoming ID matches the Priority 1 ID, subsequently received IDs will be checked only for TX INHIBIT and Priority 1 match. The effect of the above is that once a Priority 2 call is received, only a Priority 1 ID can interrupt that call while it is in progress. A Priority 1 call cannot be interrupted by another call.

Dispatch NORMAL and BLOCK Decode: If the incoming ID does not match a Priority RX ID and is then found to match the NORMAL RX ID, the transmit inhibit timer is cleared and the repeater interconnect flag is checked to see if this is an interconnect mode. If so, the "Interconnect engaged" flag is set and subsequently received IDs are checked in accordance with the next paragraph. If not, then all RX ID types will continue to be checked in the aforementioned order on subsequently received words. If the normal RX ID is not matched then the BLOCK RX ID is checked for a match. Receipt of a NORMAL RX ID will interrupt a call initiated by a BLOCK RX ID.

Interconnect ID decode: After the "interconnect engaged" flag is set as described in the previous paragraph, subsequently received IDs will be checked only for a NORMAL ID match in order to perform housekeeping. The TX inhibit ID, priority ID and block RX ID are not checked during a telephone call so that the phone call cannot be interrupted. An interconnect mode will typically be programmed with TX ID = normal RX ID and no others. Transpond is not available if the mode is associated with repeater interconnect. Interconnect is disengaged when the NORMAL (Interconnect) RX ID is received along with a turnoff code as described in section 3.5.3.

Table 3.1 RX IDs and Options

RX ID Description	Type	Number	Call	Horn	Transpond	Interconnect	
		(1-239)			(Note 1)		
Normal RX ID	required	Single	Y/N	Y/N	Y/N	Y/N	
Priority RX ID #1	optional	Single	Y/N	Y/N	Y/N	-	
Priority RX ID #2	optional	Single	Y/N	Y/N	Y/N	-	Note 2
Block IDs	optional	Block	Y/N	Y/N	-	-	
TX Inhibit ID	optional	Block	-	-	-	-	
Data RX ID	oprional	Single	Y/N	Y/N	-	-	Note 2

Legend:

Number: ID Number. If type is optional and not used, Number must be 0.
Single: Single number allowed.
Block: Contiguous block defined by start and stop Numbers.
Y/N: Yes/No programming option
NA: Not available for this type of ID.

Options: (ignored if ID = 0, i.e., inactive ID type)

Call: Turn on call light when received.
Horn: Start horn alert sequence when received if other horn alert requirements are met.
Transpond: Automatic transmission of 3 words after receipt, subject to other TX restrictions. The unit transponds using mode's TX ID.
Interconnect: Identified as a repeater interconnect mode.

Notes: 1. Transpond is not available for Mode if Interconnect column marked "yes."
2. Priority RX ID #2 is a feature of ESP500 series mobiles only. Data RX ID is a feature of the ESP520DX and ESP600 series mobiles only.

3.3 OPERATION

3.3.1 Basic Dispatch Operation on a Single System

Unless otherwise indicated, the following scenarios consider a mobile/dispatcher operator accessing a single system. The preceding 9 sync bits and the trailing 7 check bits of the trunking data words are not shown in the diagrams. It is assumed that words are received without error.

3.3.1.1 **Basic operation on HOME channel**

1. OPERATOR 50-1: turns on radio and selects Mode 1.

2. MOBILE 50-1: Mode 1 is programmed for a system with area bit = 0, home channel = 1, TX ID = 50, normal RX ID = 50. The mode data includes a total of five repeaters for this system, numbered 1 to 5, with corresponding FCC channels 1, 31, 61, 91 and 121. Radio initializes receive on home channel (repeater 1) with free channel memory = 0.

3. REPEATER 1: Is idle and transmits message every ten seconds. Otherwise off the air until traffic occurs. ID=255 indicates idle and FREE=1 (itself). Idle homed mobiles update their free repeater memory to 1 and continue monitoring with audio muted.

REPEATER #1 IDLE MESSAGE

AREA	GO-TO	HOME	ID	FREE
0	1	2	255	1

4. OPERATOR 50-1: Wishes to call his group and depresses PTT.

5. MOBILE 50-1: Checks free channel. If it is 0, it checks for carrier on the home channel and since the repeater is idle and off the air (no carrier detected), sets its own free channel to 1. If the mobile had received the idle update above, the free channel is already 1. Transmits a single word to repeater 1 indicating desire to communicate with other group 50 mobiles. Returns to receive expecting immediate response from repeater 1. All mobiles always send 31 in the PASS field, which is the same field as the repeater's FREE field.

MOBILE 50-1 DATA MESSAGE

AREA	IN USE	HOME	ID	PASS
0	1	1	50	31

6. REPEATER 1: Receives word from mobile 50-1. First checks that AREA and IN-USE match its area and repeater number. If they do, and a call validator is used in the system, it checks to see that the HOME and ID is valid. If the call is valid, it sends the following word a minimum of three times. The free channel could also be 3,4, or 5.

REPEATER #1 DATA MESSAGE

AREA	GO-TO	HOME	ID	FREE
0	1	1	50	2

7. MOBILES:

A. MOBILE 50-1: Receives word back from repeater 1 that matches the one it sent (except for FREE) which completes the mobile handshake (connection), sounds courtesy tone to operator 50-1, and then begins transmitting its original word continuously with mic audio enabled.

B. Other GROUP 50 MOBILES: Receives valid word from the repeater which matches its HOME and NORMAL RX ID, notes that it is already receiving on the GO-TO channel, and unmutes its audio upon receipt of the next valid ID. Turns on call light if so programmed, honks horn, etc. Also disables PTT button due to busy lockout condition.

C. Idle home MOBILES: Upon receipt of valid word from home repeater, these mobiles save the new FREE channel and continue monitoring.

8. REPEATER 1: Upon receipt of second valid word from mobile 50-1 which matches the first

word from mobile 50-1, the handshake connection is completed from the repeater's view point. The repeater controller enables the repeat audio, updates the FREE field if necessary and otherwise repeatedly transmits the same word.

9. OPERATOR 50-1: Finishes speaking and releases PTT button.

10. MOBILE 50-1: Detects the unkey, completes current word, then sends a final word with the IN-USE field changed to the turnoff code. Transmission is stopped and the radio switches to receive on the home channel (with free channel memory initially set to zero).

MOBILE TURNOFF WORD

AREA	IN USE	HOME	ID	PASS
0	31	1	50	31

11. REPEATER 1: Receives turnoff code in IN-USE field, disables repeat audio path, completes current word being transmitted, sends final word with turnoff code in GO-TO field, places its own number in the FREE field and goes to idle condition. The repeater may also send one or more idle words as in step 3.

REPEATER #1 TURNOFF MESSAGE

AREA	GO-TO	HOME	ID	FREE
0	31	1	50	1

12. All MOBILES besides 50-1: Receive repeater word with GO-TO = turnoff, mute their audio output, update free channel memory to 1, and continue listening on the channel. The Group 50 mobiles also re-enable PTT if a transmit inhibit ID was not received. See the discussion of the Transmit Inhibit feature in Section 4.3.5.

After the repeater sends its turnoff message, any mobile from any group homed to repeater 1 may access repeater 1 to make a transmission.

If a response to the previous group 50 transmission is required, another operator in group 50 presses PTT and steps 4 through 12 are repeated if the HOME channel is not seized first by another group. If another group seizes repeater 1 first, then trunking occurs as in Section 3.3.2 below.

3.3.1.2 **Response to signal impairments**

When signals are weak or co-channel interference is experienced, situations will arise which cause difficulties in performing the data handshake or continuing the transmission after handshake.

After the mobile (in step 5) sends its first word, it looks for repeater sync bits for up to three word lengths. If sync is not found or if repeater carrier is missing too often, or if the data checkbits continue to be bad, the mobile sends another single word to the repeater. This sequence will be repeated up to six times and if the mobile still does not decode correct words from the repeater, it sounds the intercept tone, disables PTT, and turns on the range light. The operator

then unkeys (which re-enables PTT), the mobile begins looking for words continuously and when a good one is found, turns off the range led which indicates that the mobile is back into repeater range. The mobile operator also has the option of re-keying again at any time to repeat the handshake attempt.

After handshake is complete (in step 8 above), if the repeater does not see the correct word from the mobile after 2 seconds, it will complete the current word and send the turnoff code (as in step 11 above). See section 3.4 on Repeater Interconnect for exceptions. If an unmuted mobile does not see it's own ID for 2 seconds, it will mute and return to its home channel (if not already there).

3.3.2 Operation on FREE channel (HOME Busy)

Assume Group 50 is actively occupying the home channel as in Section 3.3.1 and that another home group, 60, wishes to communicate at the same time.

1. REPEATER #1: Occupied with traffic from group 50, and is indicating that repeater 2 is a FREE channel. Repeater 2 is idle (not shown).

REPEATER #1 LOCAL WORD

AREA	GO-TO	HOME	ID	FREE
0	1	1	50	2

2. OPERATOR 60-1: Selects Mode 2 and immediately depresses PTT.

3. MOBILE 60-1: Mode 2 is programmed with area bit = 0, home channel = 1, TX ID = 60, normal RX ID = 60. Other mode data is identical to the Mode 1 used in group 50 mobiles. The mobile initializes its receiver on home channel (repeater 1) with free channel memory = 0. Detects PTT, notes FREE = 0, detects carrier present on home channel, and looks for a valid word on the home channel in order to get a good free channel. Receives good word from repeater 1 indicating repeater 2 is free. Trunks off to free channel (repeater 2) and transmits a single word as shown below. Switches to receive on repeater 2 and awaits handshake.

MOBILE 60-1 DATA MESSAGE

AREA	IN-USE	HOME	ID	PASS
0	2	1	60	31

4. REPEATER #2: Receives and validates word from mobile 60-1. It places the HOME (1) and ID (60) information on the high-speed bus and looks for another available repeater to place in the FREE field. It then finishes any word it is already transmitting (or if not transmitting, it keys the transmitter) and then transmits the following word at least three times in a row. The FREE channel could be 3, 4, or 5.

REPEATER #2 LOCAL WORD

AREA	GO-TO	HOME	ID	FREE
0	2	1	60	3

5. REPEATER #1: Sees from the high-speed data bus that repeater 2 has traffic with HOME = 1 and that repeater 3 (or 4 or 5) is free. It composes a trunked word as shown below and after completing its current word, sends the word. It also must update the free field in its next local word.

REPEATER #1 TRUNKING WORD

AREA	GO-TO	HOME	ID	FREE
0	2	1	60	3

5. MOBILES:

A. MOBILE 60-1: Receives word back from repeater 2 that matches the one it sent (except for FREE) which completes the mobile handshake (connection), sounds courtesy tone to operator 60-1, and then begins transmitting its original word (see step 3) continuously with mic audio enabled.

B. Other group 60 mobiles: Receive the trunking word from the home channel (repeater 1), switch to the GO-TO =2 channel and await a local word from repeater 2. Upon receipt of the local word from repeater 2 (see step 4), they enable their audio circuits and turn on call light, etc.

C. Idle mobiles homed to repeater 1 or repeater 2: Update their free channel memory to 3 (or 4 or 5, depending upon what each repeater is sending), and remain on their respective home channels with audio muted.

6. REPEATERS

REPEATER 2: Upon receipt of the second local word from mobile 60-1, the handshake is complete and it enables the repeat audio. It continuously sends the original local word (see step 4), changing only the FREE channel among 3, 4, and 5 as it reads the high-speed data bus.

REPEATER 1: Sends a local word at least every third word, and sends either trunked or local words in between, all the while properly maintaining the free channel field. The sequence varies with controller manufacturers; the simplest sequence just alternates the local and trunked words:

REPEATER #1 LOCAL WORD

AREA	GO-TO	HOME	ID	FREE
0	1	1	50	X

REPEATER #1 TRUNKING WORD

AREA	GO-TO	HOME	ID	FREE
0	2	1	60	X

X = 3 or any other currently free channel.

At this point, either group 50 or group 60 will unkey first. Steps 7 through 12 assumes group 50 unkeys first. Note that this sequence has no effect on the words being sent from repeater 2 until after step 11.

Steps 13 through 15 show what happens if, instead, mobile 60-1 unkeys first.

7. OPERATOR 50-1: Finishes speaking first and releases PTT.

8. MOBILE 50-1: Detects PTT release, completes current word, sends turnoff word, returns to receive on home channel 1 with free channel memory = 0 and audio output muted. The free channel memory will be updated to 1 when the mobile receives a good word from the repeater.

9. REPEATER 1: Detects turnoff code from mobile 50-1, completes current word and repeats turnoff word, placing its own number in the FREE field. It remains keyed, sending only trunked words as long as Group 60 is trunked off to repeater 2. At this point in time, repeater 1 is available for new local traffic, either from homed mobiles or other mobiles that become trunked to repeater 1.

REPEATER #1

LOCAL TURNOFF WORD

AREA	GO-TO	HOME	ID	FREE
0	31	1	50	1

(Sent once)

REPEATER #1 TRUNKING WORD

AREA	GO-TO	HOME	ID	FREE
0	2	1	60	1

(Sent repeatedly)

10. Other mobiles homed to repeater 1: Group 50 mobiles see the turnoff word, mute their audio and go idle, monitoring the home channel. All idle mobiles update their free channel memory to 1.

Assume now that no new traffic occurs and mobile 60-1 finishes.

11. OPERATOR/MOBILE 60-1: Finishes speaking and releases PTT. Mobile 60-1 sends turnoff to repeater 2, switches to receive on home channel repeater 1 with initial free channel memory = 0.

12. REPEATERS:

A. REPEATER 2: Detects turnoff from mobile 60-1, completes current word, sends turnoff with FREE = 2, then goes idle.

B. REPEATER 1: Detects from high-speed data bus that no repeaters show busy with traffic assigned to HOME channel = 1, completes current word, and goes idle with FREE = 1.

13. (From step 6 if Mobile 60-1 unkeys first.)
OPERATOR 60-1: Finishes speaking first and releases PTT.

14. MOBILE 60-1: Completes current word and sends turnoff word to repeater 2. Switches to receive on its HOME channel (1) with FREE channel equal to 0. Free channel memory will be updated to 1 as soon as a good word is received on the home channel.

MOBILE 60-1 TURNOFF MESSAGE

AREA	IN-USE	HOME	ID	PASS
0	31	1	60	31

15. REPEATERS

REPEATER 2: Detects turnoff word from mobile 60-1, completes current word, sends turnoff word with FREE = 2, and goes idle.

REPEATER #2 TURNOFF WORD

AREA	GO-TO	HOME	ID	FREE
0	31	1	60	2

REPEATER 1: Detects that trunked traffic has ceased on repeater 2, completes the current word, and continues to send only local words, while keeping the free field updated appropriately:

REPEATER #1 LOCAL WORDS

AREA	GO-TO	HOME	ID	FREE
0	1	1	50	X

X = 2 or other free channel

At this point in time, mobile 50-1 could unkey and the sequence would complete as in Section 3.3.1, Steps 10-12.

Only the simplest of trunking situations has been shown above. It should be clear that when a five-channel system is loaded to capacity, it is likely that the local and trunked words and free channels emanating from each repeater will be changing on a second-by-second basis.

3.3.3 Operation when mobile FREE channel memory = zero.

FREE = 0 can occur under several conditions:

1. ALL REPEATERS BUSY: Since all trunked controllers communicate on the high-speed data bus, each is aware of the activity of all the others. When no FREE channels are available, each repeater transmits a 0 in the FREE Channel data slot. X, Y and Z are any valid GO-TO, HOME, and ID numbers.

ALL REPEATERS DATA MESSAGE

AREA	GO-TO	HOME	ID	FREE
0	X	Y	Z	0

2. MOBILE OUT-OF-RANGE of system. This means that the mobile is unable to receive valid words from its home repeater so it is unable to receive a valid FREE channel.

3. COCHANNEL INTERFERENCE on home channel: The home channel is probably not busy but the mobile sees carrier present and is receiving only invalid words from a distant repeater on another system.

If the mobile's FREE = 0 and an operator in an idle group presses the PTT button, the following occurs: The mobile notes that its free channel memory is zero and instead of transmitting, begins checking for presence of home channel carrier and looking for words on its home channel.

If carrier is found to be absent on the home channel, the home channel is or has just become available and the free channel memory is loaded with the home channel number and the mobile enters the normal transmit handshake attempt.

If no carrier is present because the mobile is out of range of its home repeater, then the busy tone will sound after three transmit attempts. The normal transmit sequence will be considered unsuccessful after 6 tries causing transmission to cease. The intercept tone will sound and the range light will illuminate. The PTT button must be released before additional transmission can be attempted.

If carrier is not absent, and once the mobile receives a good word back with a valid non-zero FREE field, then a free channel is or has just become available. It updates its free channel memory to that value and enters the normal transmit handshake sequence on the free channel.

If the mobile gets a valid word back with the FREE field still equal zero, it initiates the busy tone and continues to receive more words looking for a valid non-zero free channel. When a good free channel is found, the busy tone ceases and the mobile enters the normal transmit handshake sequence on the free channel. The busy tone also stops if the operator unkeys.

If it is unable to receive a valid word back within three word periods (approximately 1/2 second), it loads the home channel into the free channel and enters the normal transmit sequence. This is a special case that deals with the situation of co-channel interference. Typically the repeater will hear the mobile's signal and then the repeater's response will be strong enough to override the co-channel interference.

3.3.4 Collision during handshake attempt

Another situation similar to Section 3.3.3 can arise during a handshake attempt when the mobile has actually transmitted at least one word on the free channel, receives a good word back from the repeater, but the HOME and/or ID does not exactly match (echo) the word it sent. In that case it is likely that some other mobile group seized the repeater first (before the mobile's free channel had time to update). The mobile then checks to see if the FREE field has changed. If the FREE field has changed to another free repeater it restarts the handshake sequence on the new free repeater. If the FREE has changed to zero, it ceases the handshake attempt, sounds the busy tone, and begins looking for a good free channel as in Section 3.3.3. If the FREE field hasn't changed, it continues with the handshake attempt up to a total of six times before sounding the intercept tone.

3.3.5 Operation when radio is unattended

The dispatcher or other mobiles can notify the mobile operator who has been away from the vehicle of a call in two ways. See Section 4.3.1 for Call Light operation and 4.3.2 for Horn Honk operation. The mobile can also be programmed to automatically respond to calls from the dispatcher or other mobiles via the Transpond feature, described in Section 4.3.4. The mobile can be programmed to stay powered up to receive calls or transpond for a programmable delay time after the operator turns off the ignition switch as described in Section 4.3.7.

3.3.6 Selecting operation on multiple systems

If the mobile is to operate with multiple trunked radio systems, these are separately programmed into the mobile using the Program Interface Unit/ESP DataManager and selected by the mode switch. For example, the ESP504 is capable of being programmed with up to four different systems with one home/encode group ID allowed per system.

3.4 MODE SCAN OPERATION

3.4.1 Scan enable programming

When the mobile is programmed, a system bit in the EEPROM can be set to enable the front panel scan switch or cleared to disable the scan switch. If the scan switch is to be enabled, the list of available scan modes must also be programmed. Any available scan mode must also be fully defined in the EEPROM mode memory. The above is accomplished via the Program Interface Unit/ESP DataManager. Assuming the mobile scan list includes all four modes, an ESP504 mobile can scan any combination of systems/groups or conventional channels totaling four.

3.4.2 Scan programming options

The mobile's EEPROM configuration data also allow selection between fixed or scan (float) revert, operator scan list modify enable/disable, scan resume delay period, revert weight, interval scan enable/disable and interval scan delay period during the mobile programming process. These are explained in the next section.

3.4.3 Scan feature definitions

Scan enable option - This is selected in the programming process if the scan function is to be enabled. If not selected, the scan control (SCN) is non-functional in normal operation and the following definitions are irrelevant.

Scan list - This is the mobile's internal list of modes which are scanned during scan operation. It is made up of all or some of the available modes saved in nonvolatile memory depending on whether the operator has temporarily locked out any of the available scan modes. Only the home channel of a trunked system is scanned.

Scan list modify option - If this configuration option is enabled during the dealer programming process, the operator may permanently modify the available scan modes via the front panel program (PGM) and AUX buttons. If the scan list modify option is not enabled, temporary scan lockout is still available.

Active call - When the mobile receives one of its programmed RX IDs and unmutes, regardless of current mode, this constitutes an active call. The mobile scan routine "parks" on this mode and will not drop out to the next scan list mode as long as the call continues. See scan lockout.

Scan resume delay period - This is the amount of time the mobile remains receiving on a mode after cessation of an active call, before it resumes scanning other modes in the scan list. The scan resume delay period is programmable from 0 to 9 seconds in 1-second increments. This delay is also used after PTT release and after manual mode change.

Parked - During scan operation and while receiving an active call on a particular mode, or during the scan resume delay period after cessation of an active call on a particular mode, the receiver is parked on that mode.

On/off hook - The hook switch consists of the metal button on the back of the mic which is grounded (on-hook) when the mic is placed on its (grounded) metal hanger. Scanning begins immediately when the mic is placed on hook. See interval scan for off-hook scanning option.

Revert Mode - The Revert Mode is that mode to which the mobile will switch when the mobile is scanning and the operator initiates PTT, takes the mic off hook, releases the SCN button, or cycles the radio power. The different types of Revert, such as temporary, fixed or scan, generally refer to *how* the mobile automatically selects the Revert Mode. *The operator can manually select the desired Revert Mode by turning the mode switch any time except while transmitting*.

Temporary Revert - This is the mode on which the mobile is currently parked and which the mobile will attempt to transmit on if the PTT button is depressed during the scan resume delay period. Temporary revert is independent of fixed revert. If scan revert is used, the Scan Revert Mode tracks the Temporary Revert Mode.

Fixed Revert - This is a programmable option. If this option is selected during the dealer programming process (rather than Scan Revert), the Revert Mode will be the *last mode manually selected* via the mode switch.

Scan revert - Also known as Float Revert. This is a programmable option. If this option is selected during the dealer programming process (rather than fixed revert), then if the mobile is not parked on a channel, the Revert Mode will be the *mode where the last active call was received*.

Interval delay - The interval delay is programmable from 0 to 255 seconds in 1-second increments. This delay period is invoked after the mic is taken off hook.

Interval scan - If this option is disabled during the programming process, the mobile will not scan while the mic is off hook. If this option is enabled, then when the mic is taken off hook the mobile will begin scanning after the interval delay expires if no active call is being received.

Scan dwell time - The scan dwell time is the length of time the mobile will remain listening on a given mode without receiving an active call before it drops out to the next mode. This time period can vary widely and depends on several factors. See scan dropout and revert weight. Dropout is disallowed during the interval delay and scan resume delay periods.

Scan dropout - This refers to the mobile scan algorithm which determines when to switch reception to the next mode in the scan list if no active call is received. Dropout is disallowed during the interval delay and scan resume delay periods.

Revert weight - The revert weight is a factor that is applied to the dwell time for the revert mode. The purpose is to assign higher levels of priority to calls received on the revert mode. Programmable weights range from 1 to 8.

Scan lockout - Mobile modes which are not in the current scan list are locked out. This occurs either because they are not available scan modes (dealer programming or operator scan list modification) or the operator has temporarily locked modes out. Temporary lockout occurs when the operator locks out a mode after scan has been activated. Temporarily locked out modes are returned to the scan list when scan is deactivated. Permanent lockout occurs when the operator locks out a mode while scan is not activated if scan list modify is enabled. Permanent lockout actually deletes modes from the list of available modes in the nonvolatile memory. Deleted modes can also easily be returned to the scan list. See scan list modify.

Scan program - See scan list modify and scan lockout.

3.4.4 Scan Operation Example

Assume that mobiles 50-1 and 50-2 have four modes programmed for four different trunked systems with scan allowed and all four modes in the scan list. Revert type is fixed, interval scan is enabled, scan resume delay is 3 seconds and interval delay is 6 seconds. On Mode 4 the mobiles' home channel is 1.

1. MOBILE 50-1: Operator selects Mode 1 which will be his (fixed) Revert Mode. Operator depresses SCAN button. Scanning will take place immediately if no active call is being received whether microphone is on or off hook. The mode LEDs are lit in sequence indicating which modes are being scanned. Mobile receives on the home channel of each mode (system).

2. MOBILE 50-2: This mobile has just connected on Mode 4 and is transmitting on system 4, repeater 2.

3. HOME REPEATER (Channel 1), SYSTEM 4: transmits data messages which include trunked words that instructs GROUP 50 to GO TO Channel 2.

4. MOBILE 50-1: Notes activity on the Mode 4 (system 4) home channel. Receives data message with HOME = 1, ID = 50, GO-TO = 2 which matches its RX ID on system 4. It parks on Mode 4 and tunes its receiver to repeater 2 of system 4.

5. CHANNEL 2 REPEATER, SYSTEM 4: sending data messages which includes local words that instructs GROUP 50 to GO TO Channel 2 (stay here) and unmute their audio.

6. MOBILE 50-1: Receives the data message, unmutes its audio circuits, and hears operator 50-2's voice.

7. MOBILE 50-2: Finishes speaking, sends turnoff code, ends transmission, tunes receiver back to home channel. This mobile, if scan is enabled, will remain on Mode 4 (system 4's home channel) for at least 3 seconds (scan resume delay as programmed) after unkeying.

8. CHANNEL 2 REPEATER, SYSTEM 4: Receives turnoff from mobile 50- 2, and also sends a turnoff word.

9. MOBILE 50-1: Receives turnoff code from repeater 2, mutes its audio, waits one word length, returns to home channel repeater 1 on system 4. Still parked on Mode 4. Starts its 3-second scan resume timer. Continues monitoring Mode 4 home channel for a new
active call at least until the scan resume timer expires.

The scan resume delay period is meant to provide 1) time to monitor the next party in a conversation or 2) time to respond to the previous transmission if a response is warranted. In the case of 2), the mobile is still parked, thus its temporary revert is Mode 4 (system 4) and its transmitter will correctly transmit on the last system/group received.

If a response is warranted but the scan resume timer has expired and the receiver is therefore no longer parked, the mobile will revert to Mode 1 if mic is taken off hook or PTT is depressed because it is set for a fixed revert = last mode selected = Mode 1. In this case, the operator must first intervene by rotating the mode switch to return to Mode 4 which invokes the scan resume delay (3 seconds in this example) and changes the fixed revert to 4. The operator could alternatively exit scan mode and manually select Mode 4.

If scan (float) revert was programmed instead of fixed revert in the situation above, the revert mode would have been changed to Mode 4 when the active call was received, and it would not matter whether the scan resume timer expired before transmission.

Now, if the operator takes the microphone off hook, the mobile reverts to Mode 4 and the scan interval delay time is set to 6 seconds (as programmed). If the operator does nothing else the mobile will not scan new modes for at least 6 seconds. (The radio would also revert to Mode 4 if PTT was depressed or scan was exited.)

3.5 TELEPHONE INTERCONNECT OPERATION

3.5.1 General considerations for Repeater Interconnect

Telephone calls may be placed from mobiles to the public switched telephone network (PSTN) or other landline or microwave facility if one or more of the repeaters in the trunked system are equipped with repeater interconnect equipment. Interconnect-equipped repeaters are capable of either dispatch or interconnect operation depending on the HOME and GROUP ID received in the local word.

Typically, each interconnect has hardware which mates a single phone line to a particular repeater in the trunked system. Zetron or Trident interconnected controllers may be programmed by the system operator to reserve selected HOME/GROUP ID combinations for interconnect operation. The interconnect goes off hook and provides dial tone only when one of these preselected IDs is received from a mobile.

Interconnect and dispatch operations differ in one major respect. Unlike mobile dispatch calls, an entire telephone call must take place on the same interconnected repeater because the audio for a particular telephone line is hardwired to a single repeater. Once the repeater interconnect is engaged either by a mobile-initiated or landline-initiated call, the repeater is seized continuously and it transmits continuously until the interconnected call is ended. Because no (further) trunking occurs after the initial mobile-repeater handshake, mobiles are subsequently enabled to transmit voice immediately after the PTT button is depressed during the call and their audio is unmuted immediately upon detection of carrier after unkeying.

Mobiles which are programmed to allow telephone interconnect have at least one mode programmed to have an interconnect-equipped repeater as the home channel and both the TX and normal RX IDs will match one of the preselected interconnect IDs. The mode is also marked as an "interconnect mode" so that the mobile knows whether or not handshake is required on every transmission during connection. When the mobile's mode data is programmed, each channel (repeater) in the trunked system has an associated flag that is set if that repeater is interconnect-equipped. This allows the mobile to distinguish between interconnect and dispatch-only free channels during call setup.

When using Zetron Model 49 controllers, all repeaters programmed into the mobile interconnect Mode could be marked as interconnect-equipped even if they are not, since the Zetron controller can be set to provide only interconnect-equipped free channels. This would allow later installation of additional interconnect equipment at the site without the need to reprogram mobiles.

When a mobile receives the first interconnect ID from the repeater (either as part of a mobile-initiated interconnect call handshake or when a landline-initiated call is ready at the repeater), it sets an internal "interconnect engaged" flag and its operation is subsequently modified and oriented more for interconnect operation. During an interconnect call, the mobile looks only for its normal RX ID, ignoring all other RX IDs. Mobile busy lockout is disabled. The mobile, if

trunked off its home channel, does not return to receive on its home channel until the interconnect call is completed. Due to the above, the mobile will not stray from the interconnected repeater until the call is complete.

A repeater interconnect call is successfully completed when the mobile receives a turnoff code from the repeater. This occurs after the mobile or landline end "pounds down" (transmits DTMF "#" tone) the interconnected repeater or the interconnect times out and hangs up due to inactivity or hangs up due to operator error.

When, during an interconnected call, the mobile ceases to receive valid words from the repeater (because it is out of range or experiencing other signal impairments), the mobile will be forced back to receive on its home channel with transmission inhibited for five seconds. This is known as a "lost interconnect". This provides another chance for the mobile to begin receiving interconnect IDs and return to the interconnected call.

Mobile interconnect calls are limited to half-duplex operation because the 220 MHz receive/transmit frequency difference is only 1 MHz, resulting in an impractical 0.5% mobile duplexer frequency split. More than one mobile can participate in an interconnect "conference" type call if the mobiles' mode data is identical and the interconnect hardware at the repeater is configured to repeat the audio of a transmitting mobile. Obviously, mobile operators must understand that only one mobile can transmit at a time since there is no busy lockout.

The interconnect hardware, depending on how it is programmed, can typically accept dialing information from the mobile or it can auto-dial prearranged telephone numbers. Mobiles must be equipped with DTMF microphones to employ free-form dialing.

3.5.2 Repeater Interconnect free channel determination

Mobiles are usually programmed so that one or more modes is programmed to select a home channel repeater which is interconnect-equipped. If the HOME interconnected repeater is busy when the mobile attempts to initiate a phone call, the mobile inspects the available FREE channel. If the free channel is zero, the mobile does not transmit and continues to look for a non-zero free channel as described in section 3.3.3. Depending on the sophistication of the trunking controller, the free channel will be, in the simplest case, any free repeater in the system, including dispatch-only repeaters. In this case the mobile must make use of its internal programming to determine if the free channel presented by the home repeater is actually interconnect-equipped. If it is, then the mobile can trunk off to that channel. If it is not, then the mobile sounds the busy tone and the operator must then wait for an interconnect-equipped free channel. This can be a haphazard process since the free channel field will change often and the operator must continue to key the mobile waiting for an interconnect free channel.

The undesirable situation above is alleviated or potentially eliminated by one or more of the following improvements:

1) The mobile can be programmed to have more than one mode capable of interconnect, with each interconnect mode having a different interconnect-equipped home channel. The

disadvantage is that fewer modes are then available for dispatch operation.

2) The ESP mobiles are equipped with Free System Ringback (FSRB) capability which can be made active when the home channel interconnect is busy and the free channel is not interconnect-equipped. The FSRB option may be activated during the mobile programming process. If so, then while the busy tone is sounding, the operator can press the AUX button, which enables FSRB. A 400 ms tone will sound, indicating that FSRB is armed. The operator can then unkey and wait. When an interconnect-equipped free channel is received, the mobile will ring for one second. This indicates a good interconnect free channel was received and the operator can then proceed to attempt the call. Note that ringback does not guarantee a good interconnect free channel because free channels can change often or another user may seize the interconnected repeater first.

3) The system operator can equip each system repeater with an interconnect which will usually not be cost effective especially since interconnects typically cannot share telephone lines.

4) The Zetron Model 49, if properly programmed, will transmit only interconnect-equipped free repeater numbers on interconnect-equipped repeaters. A busy tone will sound only if all interconnected repeaters are busy.

3.5.3 Repeater Interconnect Operation Example

Assume the trunked system consists of five repeaters, numbered 1 to 5, of which repeaters 1 and 2 are interconnect-equipped. The interconnect group IDs at the controllers for repeaters 1 and 2 were selected to be the block including HOME 1/GROUP 240 to HOME 1/GROUP 250. Mode 1 in the mobile is programmed similarly for this system with its "interconnected repeater" flags marked for channels 1 and 2 and its ringback system enabled. Its home channel is 1 and its TX ID equals its normal RX ID, which is 240.

At the beginning of the following scenario, both repeaters 1 and 2 are already engaged with telephone calls by mobiles both with home channels of 1 and respective IDs of 241 and 242. Mobile 242 is trunked off to repeater 2.

Mobile 240 is currently monitoring its home repeater (1) and will attempt to place an outgoing telephone call. (Note that a landline caller attempting to telephone mobile 240 would naturally get a telco busy signal since both interconnects are busy).

1. REPEATER #1: Busy with both local interconnect traffic and trunked traffic updates. (Even though there may only be one mobile on the system with group ID 242, the system does not know this and must send home channel updates.) Repeater 1 alternates the following words while repeater 2 sends only the right hand word below as its local word. Sync and check bits are not shown. The FREE channel shown below is 3 but it could be 3, 4, 5, or 0.

REPEATER #1 LOCAL WORD

AREA	GO-TO	HOME	ID	FREE
0	1	1	241	3

REPEATER #1 TRUNKED WORD
(and repeater #2 local word)

AREA	GO-TO	HOME	ID	FREE
0	2	1	242	3

2. MOBILE 240: Is monitoring Mode 1 home channel repeater 1 words and updates its free channel memory to 3. It is otherwise idle with its audio muted since the group IDs being received do not match its RX ID.

3. OPERATOR 240: Decides to make a phone call and depresses PTT.

4. MOBILE 240: Detects PTT, notes that it is in an interconnect mode and looks up repeater 3 in its list to see if it is interconnect-equipped. The repeater is not interconnect-equipped and the mobile, instead of transmitting, initiates the busy tone.

5. OPERATOR/MOBILE 240: Operator hears the busy tone and while still keyed, presses the AUX button upon which mobile 240 sounds the confirmation tone. The operator then unkeys and waits for ringback indicating an interconnect-equipped free channel.

6. OPERATOR/MOBILE 242: Operator finishes his telephone call, sends the DTMF "#" sign to cause an interconnect disconnect and unkeys. Mobile 242 sends turnoff code to repeater 2 and returns to receive on repeater 2 awaiting turnoff code from repeater 2. (Remember that Mobile 242 still has its "interconnect engaged" flag set and has no way of knowing that operator 242 has sent a disconnect command; so it must continue monitoring repeater 2 until it receives a turnoff code).

7. REPEATER 2: Receives turnoff code from mobile 242, the interconnect hangs up, places its own number in the free channel slot and retransmits the turnoff code as shown below.

REPEATER 2 TURNOFF WORD

AREA	GO-TO	HOME	ID	FREE
0	31	1	242	2

8. MOBILE 242: Receives the turnoff code from repeater 2, mutes its audio and then returns to the idle state on its home repeater (1).

9. REPEATER 1: Notes from the high speed data bus that repeater 2 is now free, stops sending trunked words, changes its FREE field to 2, and continues sending local words to mobile 241.

REPEATER 1 LOCAL WORDS

AREA	GO-TO	HOME	ID	FREE
0	1	1	241	2

10. MOBILE 240: Receives the latest word from repeater 1 which has a new FREE field = 2, looks it up in its internal list and determines that repeater 2 is interconnect-equipped, and it sounds the ringback to operator 240 for one second.

11. OPERATOR 240: Hears the ringback and immediately pushes PTT (before the new free interconnected channel gets busy again).

12. MOBILE 240: Detects PTT, looks up the free channel = 2 in its internal list and determines it is ok for repeater interconnect, switches to repeater 2 and sends the following word and then switches to receive awaiting for repeater 2's acknowledgment.

MOBILE 240 WORD

AREA	IN-USE	HOME	ID	PASS
0	2	1	240	31

13. REPEATER 2: Receives and validates the word from mobile 240, notes that it is an interconnect ID, takes the phone line off hook, gets free channel 3,4 or 5 off the high speed data bus. If Zetron controllers are used, they can, if desired, be programmed to source free channel = 0 when all system interconnected repeaters are busy. Repeater 2 sends the following local word. Repeater 1 will also send the same words as in step 1 except the trunked word ID will be 240 instead of 242.

REPEATER 2 LOCAL WORD

AREA	GO-TO	HOME	ID	FREE
0	2	1	240	X

X = 3, 4 ,5 or 0

14. MOBILE 240: Receives the matching GO-TO, HOME and ID back from Repeater 2 which completes the handshake, sounds the courtesy tone, enables mic audio, enables continuous transmit and sets its internal "interconnect engaged" flag. At this point mobile 240 will not leave repeater 2 in either transmit or receive unless a turnoff is received, interconnection is lost, or the operator intervenes by turning the mode switch, etc.

15. OPERATOR/MOBILE 240: Operator hears the courtesy tone and unkeys. Mobile begins receiving interconnect ID from repeater 2, unmutes and operator hears telco dial tone. Operator can now key up at will with no handshake required, dial the telephone number and proceed with the phone call. When the call is complete, the completion sequence is the same as it was for mobile 242 in steps 6-9. The interconnect contains activity and time-out timers which, if one expires, will also cause transmission of special progress tones, and can cause hang up and transmission of the turnoff code.

3.6 CONVENTIONAL OPERATION

3.6.1 Basic Operation

The mobile operator can select conventional operation by setting the mode switch to a mode number that has been programmed as a conventional channel. There is no special front panel indicator for conventional repeater operation.

During mobile programming, the EEPROM system trunked/conventional bit is left cleared for conventional operation. The mode is then programmed with a home channel, TX ID and RX ID(s) and a corresponding FCC channel for the home channel's repeater number. All other repeater channel slots should be left set to zero to avoid unpredictable operation.

When a mobile mode is set for conventional operation, it cannot trunk off the home channel. The mobile always receives and transmits on its home channel.

No handshake or courtesy tone is required on a non-trunked single repeater conventional system and none occurs if the mobile mode is programmed for conventional operation. If the mobile mode is programmed for conventional operation, it can also optionally be set to allow conventional talk-around. Busy channel lockout is optional on conventional modes but is usually enabled.

If repeater handshake/courtesy tone is desired on a conventional repeater system, the mobile mode can be set for trunked operation with only the home repeater channel slot programmed, all others set to zero.

Special features such as ringback, priority IDs, transmit inhibit, interconnect operation (with interconnect-equipped repeater) and transpond remain available in conventional modes. See Section 4.3.

3.6.2 Conventional operation with ESP1000 internal DTL control

If the ESP1000 repeater is programmed for standalone conventional operation (no external trunking controller in use), the repeater uses its own internal DTL logic. Except for the additional features described below, DTL operation is the same as for a trunked system. The ESP1000 internal DTL logic can send four different "FREE" channel numbers depending on its programming. FREE = 30 or 31 are unique to ESP1000 internal DTL conventional operation.

1. FREE = HOME Repeater available for any valid group.
2. FREE = 0 Repeater is busy with valid group.
3. FREE = 31 Sent during valid group hang time.
4. FREE = 30 Sent when group exceeds allotted time or is invalid.

Group hang time: (Assumes mobile mode has busy lockout enabled.) This feature allows a group to have exclusive use of the repeater for a programmable (time-out time) period. After the mobile

unkeys, the repeater changes FREE to 31 and continues to transmit for a programmable (hang time) period. If the received group matches the mobile's normal receive ID, it then also checks for FREE = 30 or 31. If it receives FREE = 31, the mobile sets its transmit free repeater to equal the home channel and PTT is enabled. Mobiles in other groups do not see their normal RX ID and interpret FREE = 31 as invalid, set their transmit free channel to zero, and disable PTT.

Receiving mobiles hear beeps warning of pending time-out beginning 30 seconds before time-out expiration. If a mobile group exceeds its repeat time limit or if an invalid mobile group attempts to access the repeater, the repeater will send FREE = 30 until two seconds after the offending mobile group unkeys. Any mobile whose normal RX ID matches the offending group ID will set its transmit inhibit timer to 5 seconds. Mobiles in a timed-out group hear "time-out" beeps until 2 seconds after the offending mobile unkeys. Mobiles in invalid groups hear nothing. The 5-second transmit inhibit period allows other valid groups an opportunity to access the repeater shortly after the timed-out group unkeys.

The time-out-timer is reinitialized each time the repeater is allowed to drop longer than the hang time or if a new valid ID is received.

Interconnect operation, as described in Section 3.5, is available when the repeater is programmed for "trunked" operation and is equipped with an external interconnect-equipped controller.

3.6.3 Conventional operation with external trunking controller-equipped repeater

When the ESP1000 is to be used as a single-repeater system but is equipped with an external trunking logic controller, the ESP1000 repeater is programmed for "trunked" operation. The repeater system will then operate as would a normal trunked system home repeater with the exception that the FREE channel is restricted to equal either HOME (available) or ZERO (busy). This configuration is used if interconnect operation is to be provided as described in Section 3.5.

3.6.4 Talk Around

Talk around (simplex radio operation on the associated repeater transmit frequency) may be enabled during programming of a conventional mode in a mobile. Talk around can then be activated (or deactivated) by pushing the AUX switch. The mode light will blink when talk around is selected. The talk around status of a conventional mode is saved in EEPROM and is therefore nonvolatile.

3.6.5 Busy Channel Lockout

During the dealer programming process, Busy Channel Lockout is automatically enabled for trunked modes and may be enabled or disabled for conventional modes. When enabled, this function disables PTT while the channel is busy. The receiver unmutes only when a programmed ID is received.

When busy channel lockout is disabled, PTT is always enabled. While the mic is on hook, the receiver unmutes upon detection of one of its programmed IDs. While the mic is off hook, the

receiver unmutes upon receipt of carrier, irrespective of the received ID.

3.6.6 Subaudible Signaling

Since ESP500 series mobiles rely entirely on DTL words for either trunked or conventional operation including talk around, the subaudible signaling is always in the form of DTL data words as described elsewhere in this specification.

For conventional operation, both mobile and repeater words will always have the GO-TO equal the HOME channel or the turnoff code. The repeater will echo the mobile TX ID if the mobile word is validated. Care must be taken that TX and normal RX IDs are compatible, i.e., they will typically be identical.

3.7 TRUNKED SYSTEM ORGANIZATION

3.7.1 General

The operation of the DTL trunked radio system is described in Section 3.2. This section will describe the organization of a trunked system.

Half of the channels in the 220 - 222 MHz band are issued in groups of five with 150 kHz separations as described in Section 2. These 5-channel groups can be used for the basis of 5-channel trunked systems. As the mobile loading of such a system increases, the system operator may want to trunk two or more five channel systems together if the additional channels are available. A single trunked system may ultimately have up to a maximum of 20 channels (four 5-channel groups).

Careful planning during the setup of the initial trunked radio system is necessary to insure that changes to the system in the future that might affect the programming of early mobiles will not occur. If a change is necessary, each radio operating on the system may require reprogramming. This planning will also help if you add more channels or combine systems at a later date.

In the initial setup stage you should coordinate with other 220 MHz license holders in your area of operation and adjacent areas whose mobiles could affect your system or interfere with your customers' communications. You should also coordinate your system setup to insure that you can provide services to roaming customers from other systems thus increasing your service offerings and providing another source for revenue. The items to be coordinated are the system Area Bit value, repeater numbering, and ID codes reserved for roamers and interconnect operation. These items are discussed in the following paragraphs.

3.7.2 Repeater Numbering

The FCC numbering scheme (Table 2.1) cannot be used to number the repeaters in a trunked system. Each repeater must be assigned a number between 1 and 20. Each number must be

assigned only once in any system. The number assignment can be arbitrary; however, the number assigned to a repeater determines its time slot in the data stream on the high-speed data bus. A numbering scheme that provides as equal a time period between each time slot as possible should be used.

Do not number your repeaters 1, 2, 3, 4, 5. Even though the licenses in the 220 MHz band are exclusive, the five channel frequency block assignment plan increases the likelihood that mobiles from a system in an adjacent area, which has the same channel block assignment, can roam into your license area, access your system and interfere with your subscribers. This can happen if repeaters operating on the same frequency are programmed with the same repeater number and area bit. In that case, roaming mobiles from other systems with a valid ID code and home channel number will be able to access your system.

The example shown in Figure 3.1 shows two trunked systems that have the same frequency assignment. This system is configured so that mobiles that occasionally travel between the two cities cannot inadvertently access and interfere with communications in the other area. System access by unauthorized mobiles is prevented because the "alien" mobiles do not receive recognizable information when tuned to their home channel frequencies. This is because the foreign repeaters are numbered differently from the systems they are programmed to operate on. The area bit may also be different.

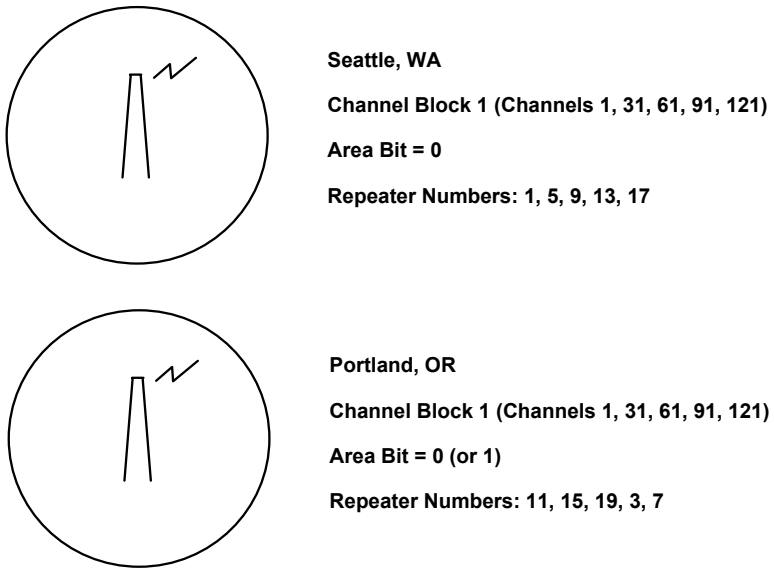
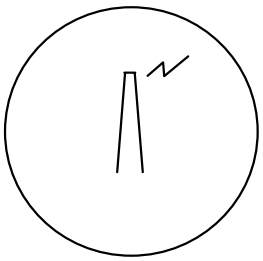


Figure 3.1 Co-channel Systems configured to avoid alien mobile problems

Figure 3.2 shows an example in which undesired access and interference from mobiles from a co-channel system can occur because of improper system setup.

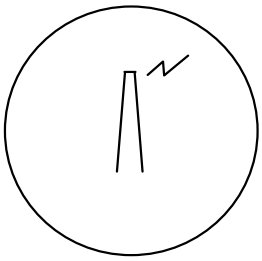


Seattle, WA

Channel Block 2 (Channels 2, 32, 62, 92, 122)

Area Bit = 0

Repeater Numbers: 1, 2, 3, 4, 5



Portland, OR

Channel Block 2 (Channels 2, 32, 62, 92, 122)

Area Bit = 0

Repeater Numbers: 1, 2, 3, 4, 5

Figure 3.2 Co-channel Systems improperly configured

When assigning repeater numbers it is recommended that you randomly select a set of five from Table 3.1. The repeater number is then programmed into the trunking controller and used in mobile programming. The instruction manual for the trunking controller describes how to program the repeater number into the controller (see 3.6.1).

Table 3.1 Repeater (R/T) Numbering Chart

SET	1st R/t	2nd R/T	3rd R/T	4th R/T	5th R/T
A	1	5	9	13	17
B	2	6	10	14	18
C	3	7	11	15	19
D	4	8	12	16	20
E	5	9	13	17	1
F	6	10	14	18	2
G	7	11	15	19	3
H	8	12	16	20	4
I	9	13	17	1	5
J	10	14	18	2	6
K	11	15	19	3	7
L	12	16	20	4	8
M	13	17	1	5	9
N	14	18	2	6	10
O	15	19	3	7	11
P	16	20	4	8	12
Q	17	1	5	9	13
R	18	2	6	10	14
S	19	3	7	11	15
T	20	4	8	12	16

3.7.3 Area Bit

The Area Bit is described in 3.2.11.1. This number is usually "0" unless there is the possibility that there is a nearby system with the same channel block assignment. In that case one system should use "0" and the other "1". Area Bit selection and repeater numbering, described above, will reduce the possibility that mobiles could inadvertently access another system when roaming.

The Area Bit value should be chosen when the system is initially set up. Changing the Area Bit value after the system is operational will require all mobiles operating on the system to be reprogrammed. This can be a costly and time-consuming task and disruptive to your customer's radio communications. The Area Bit is programmed in the repeater's respective trunking controller. The trunking controller instructions describe how to program the Area Bit.

3.7.4 Trunking Synchronization

One controller in the system must be programmed to provide the synchronization for data communications on the controller's high-speed trunking control data bus (see 3.2.2). The trunking controller instructions describe how to program the synchronization.

3.7.5 Automatic Station Identification

Federal Communications Commission regulations require trunked systems to automatically perform station identification every 30 minutes. The identification is to be transmitted on the lowest frequency channel in the system. Automatic station identification is controlled by the trunking controller. The trunking controller instructions describe how to program the automatic station identification.

3.7.6 Frequency Control

The ESP1000 is a synthesized transceiver and can be programmed to operate on any authorized frequency in the 220 - 222 MHz band. Each ESP1000 repeater operates on a single channel pair consisting of one transmit and one receive frequency. The operating frequencies of each repeater are programmed into the repeater through the front panel keypad. The ESP1000 Instruction Manual describes the procedure for programming the repeater operating frequencies.

3.7.7 ID Codes

There are 250 ID codes[2] that can be assigned to each HOME repeater in a system. The ID code can be thought of as an "address" or "telephone number" for an individual user or a talk group or fleet. ID codes can be assigned to separate talk groups, subgroups, or individual radios. The ID codes are unique and allow the mobiles in a talk groups to call each other without interfering

[2] LRT-Net® uses ID numbers 1-239 for group IDs. Codes 240-250 are reserved for special purposes. To maintain the ability to transition from LTR® to LTR-Net® in the future without the need to reprogram legacy mobiles, use only group IDs 1-239 when setting up LTR mobiles. LTR and LTR-Net are registered trademarks of Transcrypt International.

with and without being overheard by any other talk groups. An ID code can be assigned to as many users as are required to communicate with each other in a talk group. An ID code can be assigned to as few as one user for interconnect operation.

Adding a new user to your trunked system requires a determination of how many ID codes will be required. A diagram of the user's organization and communications requirements can help determine the number of ID codes needed. An index of the mobiles and ID codes assigned to each repeater should be maintained to show the loading of each repeater and the ID codes that have been used. A sample of an ID code index is shown in Table 3.2. A copy of this index should be maintained for each repeater. Mark the ID with a "T" if it is used for telephone interconnect.

Table 3.2 Index of ID Codes Site:_____

Repeater Number:_____ Date:_____

Code	User	Code	User	Code	User	Code	User	Code	User
1		51		101		151		201	
2		52		102		152		202	
3		53		103		153		203	
4		54		104		154		204	
5		55		105		155		205	
6		56		106		156		206	
7		57		107		157		207	
8		58		108		158		208	
9		59		109		159		209	
10		60		110		160		210	
11		61		111		161		211	
12		62		112		162		212	
13		63		113		163		213	
14		64		114		164		214	
15		65		115		165		215	
16		66		116		166		216	
17		67		117		167		217	
18		68		118		168		218	
19		69		119		169		219	
20		70		120		170		220	
21		71		121		171		221	
22		72		122		172		222	
23		73		123		173		223	
24		74		124		174		224	
25		75		125		175		225	
26		76		126		176		226	
27		77		127		177		227	
28		78		128		178		228	
29		79		129		179		229	
30		80		130		180		230	
31		81		131		181		231	
32		82		132		182		232	
33		83		133		183		233	
34		84		134		184		234	
35		85		135		185		235	
36		86		136		186		236	
37		87		137		187		237	
38		88		138		188		238	
39		89		139		189		239	
40		90		140		190		240	
41		91		141		191		241	
42		92		142		192		242	
43		93		143		193		243	
44		94		144		194		244	
45		95		145		195		245	
46		96		146		196		246	
47		97		147		197		247	
48		98		148		198		248	
49		99		149		199		249	
50		100		150		200		250	

3.7.8 Adding Repeaters to an Existing System

When the level of service on an existing system begins to diminish due to excessive loading, the system operator must either cease adding customers to the system or add new channels. When adding new channels, remember that the mobiles using the system must be programmed with ALL of the repeater numbers and frequencies used in the system. If this is not done, mobiles will be instructed by the system to trunk off to repeater numbers that they are not programmed for and messages will be lost.

Reprogramming of large numbers of mobiles is time consuming and costly so it is recommended that, whenever possible, to program radios with the extra repeater numbers and frequencies when originally installed. Of course, one must need to know in advance what the frequencies will be. Be aware that having the mobiles programmed with the extra frequencies in advance of installing the repeaters will not cause operational problems.

When planning to add new channels to a system and the installed user base of radios will require reprogramming, start the reprogramming as soon as possible in advance of enabling the new repeater channels. That way new repeaters can go on line one at a time, permitting system testing as the upgrade progresses, and legacy mobiles will continue to operate properly.

3.8 VOICE DISPATCH SYSTEMS EXAMPLES

This section will illustrate some examples of how to organize a customer's fleet of mobiles to perform voice dispatch on your trunked system. When first designing a radio system for your customer you should be sure that the customer's future communications needs are considered as well the initial needs. This planning will help you in making full use of your trunked system's capabilities.

The programming and use of the mobile's features will also be described in this section. The operation of the mobile's features is described in section 4.3. These features include CALL and RNGE (range) lights, Ignition Sense, Horn Alert, Battery Saver, Transpond, and Transmit Inhibit.

3.8.1 Construction Company

The owner of a construction company has a control station at the company office. Three trucks and his sedan are equipped with radios. The owner wants the dispatcher and all mobiles to be able to talk to each other. He also wants to be able to talk to the dispatcher without the other mobiles listening to the conversation.

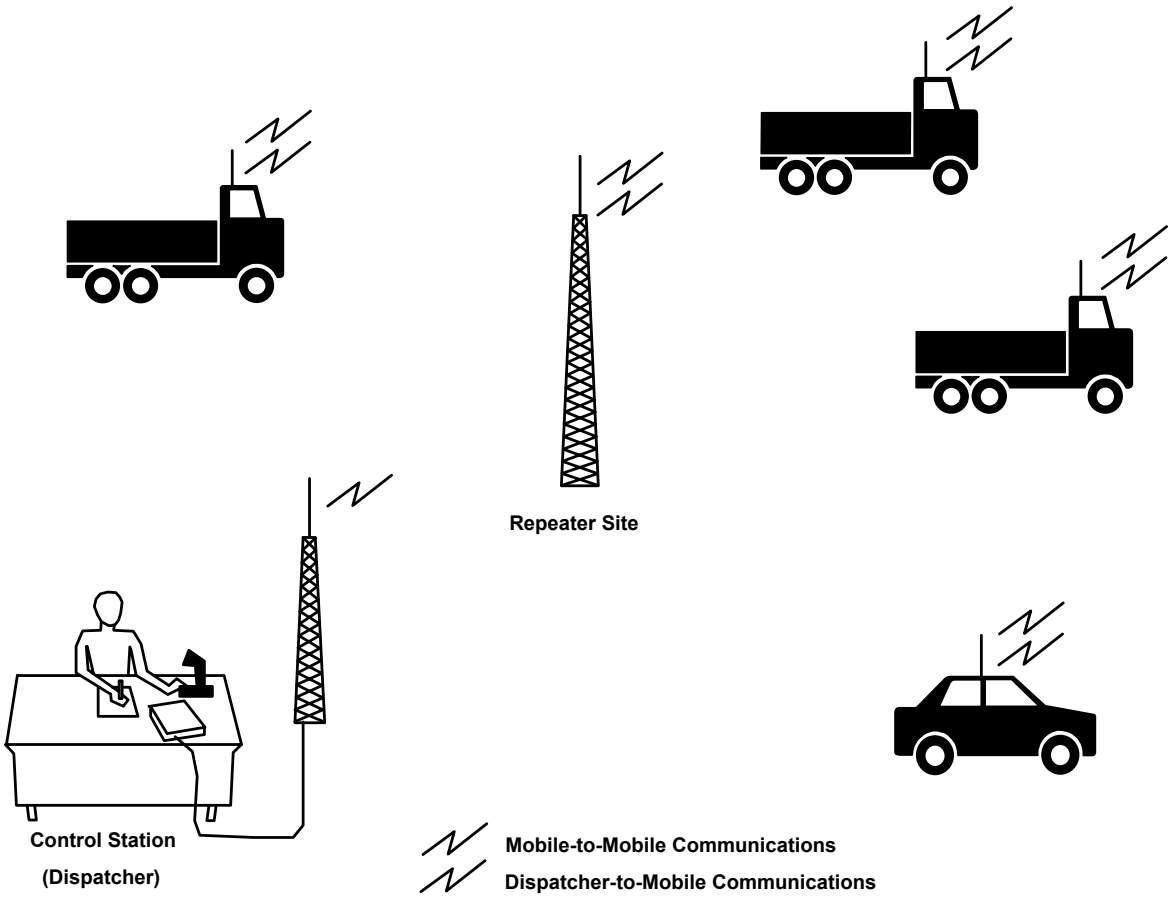


Figure 3.3 Construction Company Example

This system will require two dispatch ID codes. For each mode described in this example, the transmit ID code and the receive ID code are identical. The codes are assigned as follows:

All call = ID code 10
Owner = ID code 11

The control station transceiver and the owner's mobile are programmed for two-mode operation. Mode 1 is programmed for ID code 10 and Mode 2 is programmed for ID code 11. The single mode in each construction vehicle mobile would be programmed for ID code 10.

The owner and dispatcher's mobiles are also programmed to permit scan operation. The dispatcher's mobile is programmed for fixed revert (reverts to all call mode) while the owner's mobile could be programmed for scan revert (reverts to last mode selected or received).

With this programming the dispatcher can talk to all the employees including the owner on Mode 1. The employees can talk between themselves on Mode 1. The owner is also included in this talk group. Only the owner and dispatcher can call or be called in Mode 2. The employees cannot hear the conversations between the owner and the dispatcher on this mode. The employees can continue to talk among themselves even when the dispatcher and owner are in conversation.

The mobiles operating on Mode 1 do not need to be programmed for call light operation. If this feature was enabled the call light would light every time anyone transmitted but would not indicate which mobile was called. However, Mode 2 in the owner's mobile could be programmed for call light operation. This will alert the owner that the dispatcher called while the owner was away from the vehicle.

The mobiles can be programmed and installed for Ignition Sense operation. This would allow the operators to leave their vehicles unattended at construction sites with the radio on, without the keys in the ignition. If so programmed and the HRN button is depressed, the horn will sound when calls are received. Ignition Sense should be enabled and properly installed. This feature will turn the radio off after the programmed time expires.

3.8.2 Courier Company

The manager of a local courier company has four vehicles equipped with radios. The manager wants the dispatcher to be able to call, and be called, by each of the courier vehicle operators, but the manager does not want the operators to be able talk to each other.

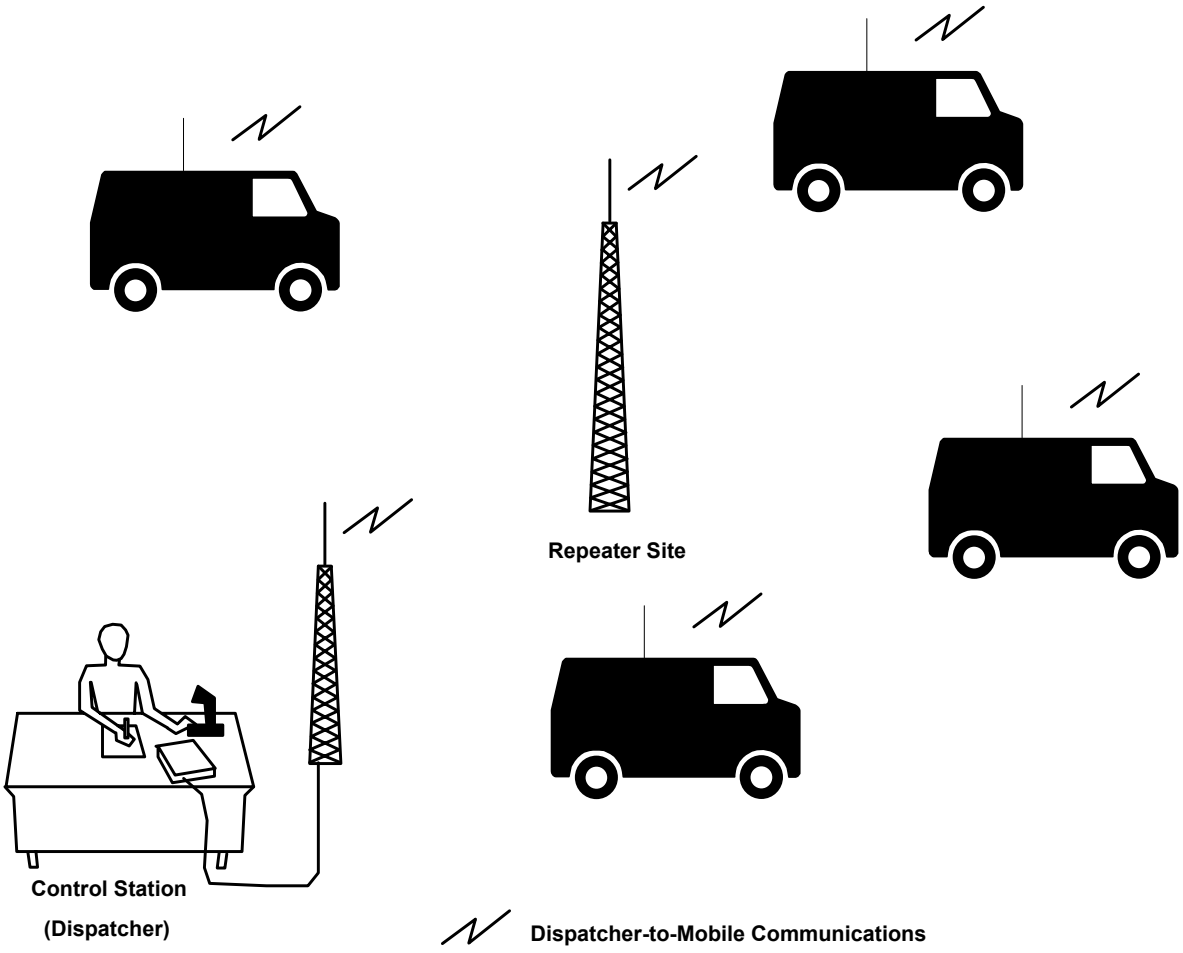


Figure 3.4 Courier Company Example

For this system four dispatch ID codes are required. For each mode described in this example, the transmit ID code and the receive ID code are identical. The codes are assigned as follows:

Vehicle One = ID code 20
Vehicle Two = ID code 21
Vehicle Three = ID code 22
Vehicle Four = ID code 23

The control station radio is programmed for four-mode operation. Mode 1 is programmed for ID code 20, Mode 2 for ID code 21, Mode 3 for ID code 22, and Mode 4 for ID code 23. Additionally, the dispatcher's radio would be programmed for scan and scan revert. The scan list will include all four modes, which allows the dispatcher's mobile to scan for calls from each of the mobiles.

Each courier vehicle's radio is programmed with its own personal ID code. The mobiles are also programmed and installed for Ignition Sense operation. This allows the operators to leave their vehicles unattended with the radio on (without the keys in the ignition) while they make deliveries. The CALL light function is enabled for each of the mobiles. Upon returning to an unattended vehicle, the operator will know whether or not they were called while away. Proper installation and programming of the Ignition Sense feature will turn the unattended radio off after the programmed time expires and reduce the chances of a dead battery if the radio is left on overnight.

The manager does not want the horn alert feature because the delivery vehicles operate primarily in congested areas and doesn't want the horn to sound and startle a passerby.

The RNGE (Range) light will help those far-ranging delivery vehicle drivers to know when they are beyond the limits of their radio system's coverage area.

On some occasions the manager also wants to know if a vehicle is in radio range when the driver does not answer a call. The mobiles can be programmed to "Transpond" when the mobile receives a call using a specific ID code. The transpond function causes the mobile to respond to the call by automatically transmitting for one second. The dispatcher will hear the mobile's automatic transmission. This allows the dispatcher to know that the radio is in range and receiving properly. If there is an abnormally long period where the driver does not answer, the dispatcher can alert a supervisor that someone may need help. The transpond ID code can be the same as the normal ID code or a different ID code. If the normal ID code is programmed for transpond the dispatcher will receive a transpond after each call to the mobile.

3.8.3 Cable Television Company

A local cable television company has five vehicles. The construction crews use two of the vehicles, two are used for new service installations and the repair crew uses one. The mobiles in the construction and service groups must be able to talk to the other mobile in their own group to coordinate their jobs. On occasion, one or all the crews in one group will work with other groups.

In these instances, the mobiles must be able to communicate with any other group. The mobiles must also be able to communicate with the dispatcher. The work crews usually start the day with scheduled jobs. New jobs are rarely sent to the work crews during the day. The dispatcher normally talks only to the repair crew on a regular basis during the day, but must be able to talk with each group. The dispatcher should hear only those calls directed to him.

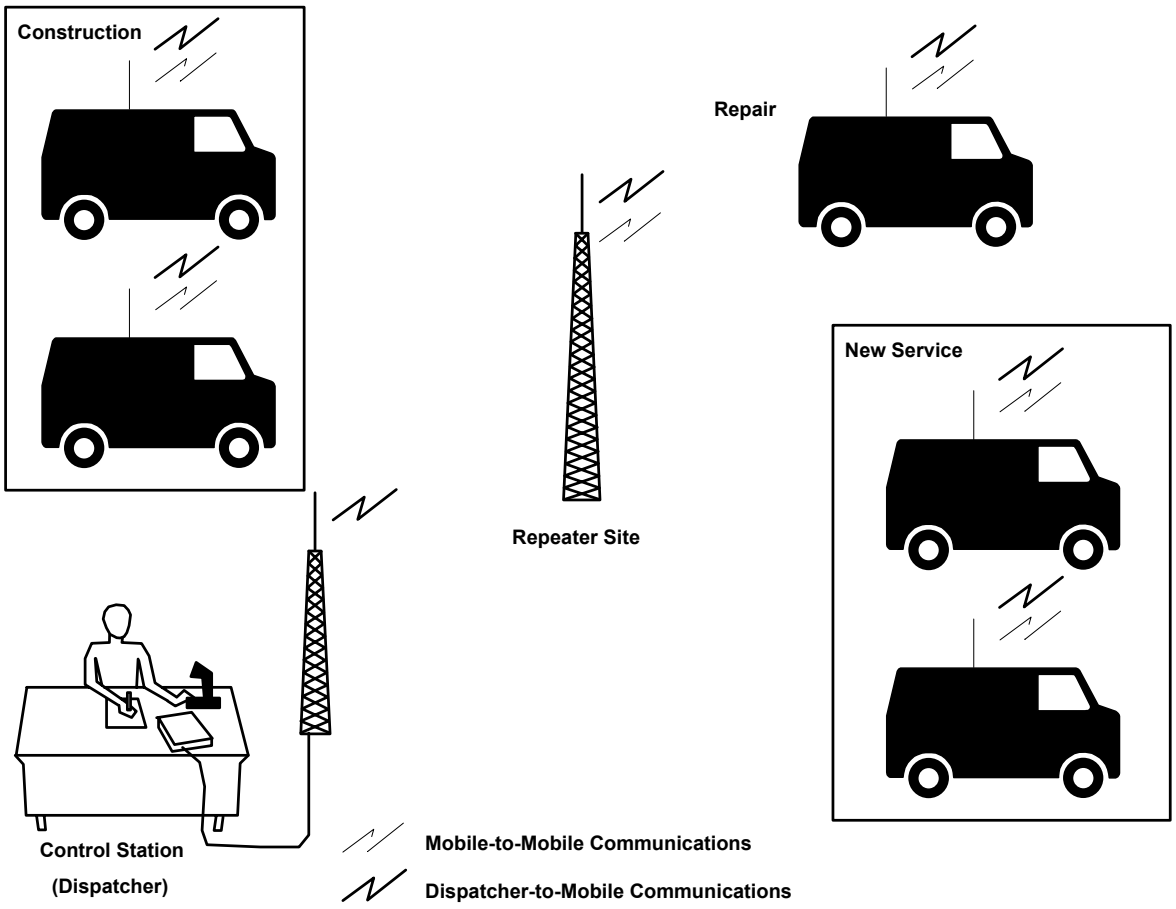


Figure 3.5 Cable TV Company Example

For this system four dispatch ID codes are required. The codes are assigned as follows:

Dispatcher =	ID code 40
Service =	ID code 41
Construction =	ID code 42
Repair =	ID code 43

The control station radio and the mobiles are programmed for four mode operation. Mode 1 would be programmed for ID code 40, Mode 2 for ID code 41, Mode 3 for ID code 42 and Mode 4 for ID code 43. The radios are programmed for scan and fixed revert. The dealer programmed scan list will include all four modes, which allows the mobile to scan for calls from any group. The mode used to call and receive the dispatcher has the call light enabled.

During normal operation, users of this system would not typically be scanning modes. Rather, each group would select its assigned mode to monitor. The operators could modify the scan list in their mobile so that only their ID code and the dispatcher's code are scanned. When necessary, an operator could restore the deleted modes to his or her scan list.

3.8.4 Appliance Repair Company

An appliance repair company has a sales office in a major city and a branch office in a smaller nearby town. The company retails appliances and provides delivery, installation, warranty and non-warranty repair, and has maintenance contracts for periodic service. Service personnel work out of both locations. All service work is scheduled at the main office, but both offices have dispatchers for communicating with the service vehicles for customer service requests. The service personnel and their vehicles supplement the work force in the other area and frequently drive to the other service area.

Because of the separation between the service areas, one radio system does not cover both cities. The dispatchers are on separate radio systems and the mobiles in the vehicles must be capable of operating in both radio systems.

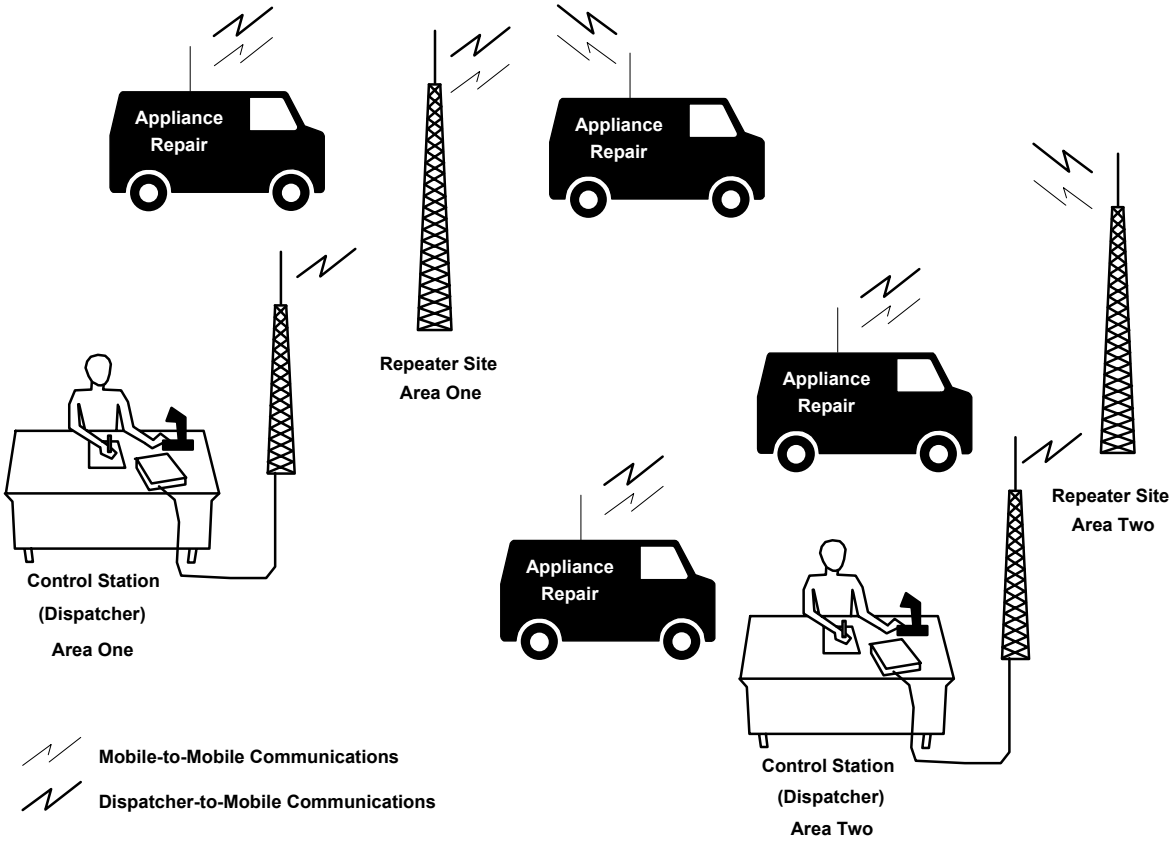


Figure 3.6 Appliance Repair Company Example

For this system four dispatch ID codes will be required. The codes would be assigned as

follows:

Dispatcher Area One	=	ID code 55
Service Area One	=	ID code 56
Dispatcher Area Two	=	ID code 20
Service Area Two	=	ID code 21

The service vehicle mobiles are programmed for operation in both radio systems. The mobiles will have Mode 1 programmed for the repeater numbers, area bit, home channel and ID code for the radio system in Area One and Mode 2 programmed for the repeater numbers, area bit, home channel and ID code for the radio system in Area Two. The mobiles are programmed for scan with fixed revert and call light operation. The dispatchers' radios will be programmed only for the radio system in their respective area. The dispatchers' radios are programmed for call light operation.

3.9 MOBILE DATA

3.9.1 Introduction

The ESP520DX and ESP600-series mobiles are full-featured and versatile radios capable of supporting data operation. These radios are designed primarily with voice communications in mind, and therefore are equipped with features that are essential for modern voice dispatch. In some cases these features should not be used in conjunction with data operation. For instance:

1. Scanning: Scanning modes/systems for mixed voice and data calls will result in lost calls and will therefore ruin the reliability of data messaging. When data modes are in use, scanning should not be employed.

2. Trunking: For pure data operations (no voice), trunking is unnecessary. Combining voice and data on the same mode is discouraged. Note that the trunking protocol adds another layer of channel access processing and airtime usage to a data transmission. For short messages, the trunking protocol set-up time will significantly reduce the capacity of the channel for data. This may be acceptable for small fleets[3]. The best kind of data system incorporates the use of dedicated conventional channels.

3. Repeater operation: For best data message reliability, the data dispatch repeater should be used as a dedicated full duplex base station, hard-wired to the dispatch point. The repeater is then used for outbound transmissions to mobile or remote units and receives only transmissions from the same. This way, the dispatch point-to-base station link is of the utmost integrity and reliability, unaffected by noise or interference. It also avoids airtime contention between the dispatcher and responding mobile/remote units. The mobiles must use external modems in this case.

Scanning data modes is not recommended under any circumstances. Trunking is acceptable for

[3] See section 4.13 Channel Hold for a description on how to mitigate trunking setup time delays in data systems that use acknowledgments or other immediate unit responses.

data systems using relatively slow data rates, such as 1200 bps, but is not available for higher data rates (2400-9600 bps). Likewise, full duplex base station mode is generally only worthwhile or necessary when using the higher data rates.

Please visit the SEA web site (http://www.sea-dmi.com/) for application note downloads concerning data applications. These application notes cover the integration of SEA data-compatible mobiles with other manufacturers' mobile data equipment. Also, consult the respective SEA Instruction and Programming manuals for information on how to set up your SEA 220 MHz equipment for mobile data applications.

3.9.2 Data Dispatch Systems

Data dispatch applications are generally assumed to be two-way, that is the dispatcher and remote vehicle are able to both transmit and receive each other's transmissions. The goal for the customer in most mobile data applications is to automate the command and response of a dispatch system. For the dealer or system operator there will be several objectives, which lead to customer satisfaction:

High level of data integrity

This means the message will get through without many re-tries. The message is received in a timely manner and the system does not have to re-send the message multiple times (tying up the system) in order to get the message through. This usually means some level of error correction is used. Another issue that affects data integrity is the data protocol. When the protocol is sophisticated enough to avoid message collisions, data is more often delivered as desired and expected.

High capacity of mobiles supported per channel

Obviously, capacity is related to data integrity discussed above. If units are re-trying messages and the system gets tied up, the result will be a low-capacity system. Other issues are at play here, as well. As a general rule, the data rate can influence the capacity of the system. It stands to reason that a higher data rate will result in more bits through the channel and, therefore, more units supported. This is true as long as you can maintain a high RF signal-strength environment. Higher data rates require the use of higher-level modulation types (e.g., QPSK or 16QAM, which might support 4800-9600 bps) which need higher signal strengths to maintain acceptable bit error rates than lower-level modulation types (MSK or GMSK, which might support 1200-2400bps). Furthermore, higher-level modulation types are more susceptible to impairments by multipath fading. So, generally speaking, as the data rate increases, the range and coverage decrease or the system capacity may not rise as expected due to retries.

Consult with your mobile data system vendor regarding the above and other system aspects that will influence the effectiveness of your mobile data applications.

3.9.3 Automatic Vehicle Location Systems

Automatic vehicle location (AVL) applications tend to be one-way (mobile to base) but can be two-way. Two-way AVL is a system where the base unit either polls individual units to report or will initiate a timing sequence where all units in range of the system can begin reporting in. It is best to avoid polled systems because the base unit will consume airtime and therefore reduce

mobile capacity. Since nearly all modern AVL reporting units utilize GPS location technology, a highly accurate real time clock is usually available at the mobile unit so timeslot allocation for reporting is made easy.

Remember that the more often the mobile units report their position, the fewer mobiles the system will support. When selecting an AVL system for a particular application, it is important to analyze the time length of the data transmission and the setup time of the repeater or base station. Keep in mind that the trunking system setup time can take longer than the actual data message. That is not to say that you should not put AVL or data applications on existing trunked systems. For instance, if the AVL application involves only a few units, there should be no problem just treating it as incremental trunked traffic. If, however, you plan on selling AVL aggressively and heavily loading your system with such traffic, you need to carefully analyze how this will impact the capacity of your system as well as the level of service to your existing (voice traffic) customers. In such cases, SEA recommends that a channel be dedicated for AVL operation and removed from trunked traffic service.

3.10 SYSTEM PROGRAMMING AND DATABASE DESIGN

The ESP600 series mobile radios are dealer-programmed using DataManager software that makes use of database storage and retrieval of information. This section contains information that will make setting up a database easier.

The database has two main sections. One section contains the information about the customers and the radios. The second section has the *system information*; it has the sites and coverage areas information.

The customer and radio information is organized around the FLEET concept; that is, a single radio configuration may be programmed into many radios. As an example, all the drivers of Frank's Towing would use the same *configuration*. One might define "Frank's Towing" as the customer. "Frank's Towing Drivers" would be one *configuration* and "Frank's Towing Dispatcher" would be another *configuration* of Frank's Towing.

An alternative way to setup the radio information is to use the radio's serial number (or some other tracking tag). One could choose a customer name like "All My Customers" or "Radios in Seattle". Then use the radio's serial number as a configuration name. Organizing the information in this way will create a database record for each radio, realizing that a large number of radios will create a large database.

The *system information* contains the *sites* and *coverage areas* information. The first thing to do after creating a new database is to open the SITE screen and create the sites to be used by any of the radios associated with the database. Enter all data regarding repeater numbers, channels, and RIC settings. Don't forget to enter repeater information for repeaters that are not installed yet but will be installed. Once this information is defined, enter it into the database. New sites can be added at any time.

Next the *coverage areas* are defined. A coverage area is simply a list of sites, which can be a helpful organization tool to define specific areas of coverage for sales purposes and system planning. When programming a radio's configuration data, a coverage area must be selected. Then when programming modes, any one of the sites (and only those sites) in that coverage area are available for selection. Sites can be assigned to a coverage area by geographical area (e.g., the sites in King county, WA) or by customer (e.g., all the sites that Frank's Towing will use). If use of the coverage area convention is not desired simply put all available sites into one coverage area to be used by all mobiles. There can be from 1 to 50 sites in a single coverage area.

4. STANDARD MOBILE FEATURES

4.1 CALL LIGHT

When the mobile receives a valid word that matches one of the RX IDs in its current mode, it unmutes and the associated call light status for that ID is checked. If the call light was programmed to be enabled for that ID, it is illuminated, and it remains illuminated until the operator changes any user input, (except volume) on the radio, such as PTT, hook, mode, etc. The call light is activated after reception of the second received word matching the receive ID.

4.2 HORN ALERT

When the mobile receives a valid word that matches one of the RX IDs in its current mode, it unmutes and the associated horn alert status for that ID is checked. If horn alert was programmed to be enabled for that ID, and (in the case of the model 504 and 604) the horn button is in the depressed position, and the back panel accessory input line is low (indicating ignition switch is off or not connected), the horn honk sequence is initiated. Horn alert consists of three "honks" (i.e., ground closures of the rear panel horn honk line) each 1 second long and separated by 1 second. Any adjustment made to the radio (except volume) during the horn alert sequence causes the sequence to be aborted. Both call light and horn honk can be enabled for a particular RX ID. Horn alert is activated after reception of the second received word matching the receive ID.

4.3 TIME-OUT-TIMER

The length of time the mobile can transmit continuously is selected during the dealer programming process (programmable from 0.5 minute to 8 minutes in 0.5-minute increments). If this time limit is reached while transmitting, the mobile automatically ceases transmitting and sounds the transmit timer expired warning until the operator unkeys.

The main purpose of the T.O.T. is to prevent inadvertent keying of the mobile transmitter for excessive periods of time, which would tie up a repeater and possibly damage a transmitter. It also can be used to keep users' messages concise.

4.4 TRANSPOND FUNCTION

Priority and normal mobile RX IDs can optionally be marked during mobile programming to allow transpond operation upon receipt of that ID. The transponding mobile first waits for the incoming call to drop out (turnoff code must be received) and then transmits back three words on its free channel, with the third word containing the turnoff code. This results in the home channel sending a few local or trunked traffic words depending on whether the transponding mobile trunked off its home channel. No handshake occurs and thus the mobile mic audio is not enabled

during this process.

The inquiring mobile's call light is usually programmed to illuminate upon receipt of the transponding mobile's TX ID thus providing an indication to the inquiring mobile that the transponding mobile is monitoring the system. Transpond can be used continuously in conjunction with regular dispatch if the system operator doesn't mind the extra air time used.

A transpond request will be canceled under the following conditions: 1) the operator of the transponding mobile depresses PTT, changes modes, or cycles radio power before transpond begins; 2) the transponding mobile is engaged in an interconnected call; 3) the transponding mobile is unable to find a valid non-zero free channel after monitoring the home channel for several word lengths.

4.5 TRANSMIT INHIBIT FUNCTION

Transmit inhibit involves use of the mobile's internal transmit inhibit timer. This timer is usually expired (cleared to zero). Transmission is disallowed when the timer is not zero. The timer counts down toward zero only while the PTT button is not depressed. *The timer is normally cleared to zero every time the received ID is found to match the normal RX ID*, while "interconnect engaged", after a mode change, and upon radio power-up. Also see 3.6.2.

Transmit inhibit is optionally enabled by setting up a TX inhibit block RX ID (from 1 to 250) during the mobile mode programming process. Each time the mobile receives an ID in this block, the transmit inhibit timer is set to 5 seconds. The TX inhibit timer is immediately cleared back to zero if the received ID does not also match either of the mobile's optional priority RX IDs but **is** found to match the mobile's normal RX ID.

The transmit inhibit RX ID block can be set in a fleet of mobiles so that a dispatcher can simultaneously converse with a selected mobile or mobile group and temporarily inhibit transmission by mobiles in the rest of the multi-group fleet. The block RX ID decode block can be used in conjunction with TX inhibit so that all mobiles in the fleet can continue to monitor all dispatcher transmissions.

4.6 AUDIBLE KEYBOARD FEEDBACK

Audible keyboard feedback occurs only during special situations such as ringback confirmation and during volume set tone after power-up.

4.7 IGNITION SENSE OPERATION

If the ignition sense option is selected during the dealer programming process and the rear panel accessory terminal is wired to the ignition switch, the main radio circuits will turn on and off according to the ignition switch setting, assuming the mobile front panel power switch is left on.

Alternately, if the ignition delay timer (also known as the turn-off timer) is selected to be non-zero (programmable from 1 to 128 minutes in 1-minute increments) the main radio circuits will remain on for that duration after the ignition is turned off.

The ignition sense option must only be selected if the accessory terminal is wired to the ignition switch (or some other 12-volt point), otherwise, the radio will never turn on.

Note that as long as primary power is available to the radio, then any time the front panel power switch is on, the microcomputer is active.

4.8 BUSY CHANNEL LOCKOUT

This EEPROM bit is dealer programmed on a mode basis. If this bit is set, the mobile may not transmit on the current mode while an active call is being received. This is the normal condition for trunked radio systems.

4.9 TRUNKED/CONVENTIONAL SELECTION

As the dealer programs each active mode, this bit is set or cleared depending on whether the mode is for a trunked or conventional system, respectively. The main difference is that trunked operation requires handshake upon transmission and conventional operation does not.

4.10 BASE STATION FREQUENCY TRACKING

Mobiles automatically update their frequency control memory so that their transmit and receive frequencies are typically within 55 Hz (+/-0.25 ppm) of the repeater frequency. Each mode has a separate frequency control memory to accommodate different repeater systems. The frequency tracking algorithm updates under the following conditions: Receipt of the proper area bit for the current mode, with the GO-TO field containing the turnoff code and the home and free fields containing the mobile's home channel number. Frequency updating is disallowed during talk-around (direct communication with other mobiles).

4.11 RANGE LIGHT

The range light is illuminated under two conditions: 1) no valid words have been received from the home channel of the selected mode during the past 30 seconds, or 2) during a mobile initiated handshake sequence if the mobile is unable to receive a valid word back from the repeater after six transmit tries. Receipt of a valid word turns off the range light. The range light is also extinguished and the range timer reset to 30 seconds when the mode is changed either manually or automatically (during scan). Mobiles may still engage in talkaround communications (if programmed) when out of repeater range.

4.12 CHANNEL HOLD

The ESP600 family radios provide a special feature known as "channel hold" or "data hold" for enhancing trunked repeater system data operation on two-way data systems while using normal trunking controller features. Channel hold uses repeater trunking controller hang time to allow an acknowledgment (or additional data exchanges, if the responding mobile is also programmed for channel hold) to be sent back on the same trunk as a data message just received. This is accomplished by eliminating the turnoff code from the end of mobile transmission and enabling the receiving mobile to initiate data transmission on the current repeater even while receiving a valid data ID. The repeater hang timer must be set appropriately to keep the repeater on the air for several hundred milliseconds to allow the receiving mobile a chance to initiate transmission before the trunk is cleared by the controller. This technique allows greater data transfer efficiency, for data systems which required an acknowledgment (handshake) and especially for multiple packet data transfers because only one trunk setup period is required for the entire data exchange. Channel hold, if enabled by the Data Manager, applies only to data transmissions on trunked repeater systems.

4.13 TALKAROUND

Talkaround permits the mobile operator to transmit on a repeater output frequency. This allows mobiles tuned to the correct frequency to receive the transmission without using the repeater; in essence *talking around* the repeater. Mobiles communicating in talkaround are operating on a simplex frequency, where the mobile transmit frequency is the same as its receive frequency. This feature is useful for situations where two or more vehicles have traveled outside range of a repeater or repeater system and still need to communicate with one another.

Unfortunately, using the talkaround feature can result in interference to other mobiles operating in the fringe area of their associated repeaters. If the mobile talkaround transmitter signal is stronger than the received signal from the repeater, victim mobiles will hear the talkaround signal if the trunking word matches or mute if it doesn't. Monitoring the channel before making a talkaround call does not necessarily reduce the likelihood of causing interference. Furthermore, using talkaround can cause interference to another licensee's operation.

The best way to mitigate the potential for interference is to inform mobile operators of specific areas where talkaround is permitted on specific frequencies.

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5. ANTENNA SYSTEMS

5.1 FIVE-CHANNEL TRUNKED GROUP ANTENNA SYSTEM HARDWARE

The chief purpose of the multi-channel antenna system is to permit multiple receivers and transmitters to share a single antenna without causing self-interference or interaction between transmitters. Commonly it is found that antenna space at a repeater site is at a premium and it is often necessary to use a single antenna for a multi-channel system. In some cases, the use of multiple antennas is practical and therefore the antenna system design used might be quite different from that described here.

The recommended antenna system for a five channel trunked group in the 220 MHz band is composed of the following:

- a five branch cavity-type combiner,
- a multichannel duplexer,
- a receiver multicoupler, and
- a single transmission line and antenna.

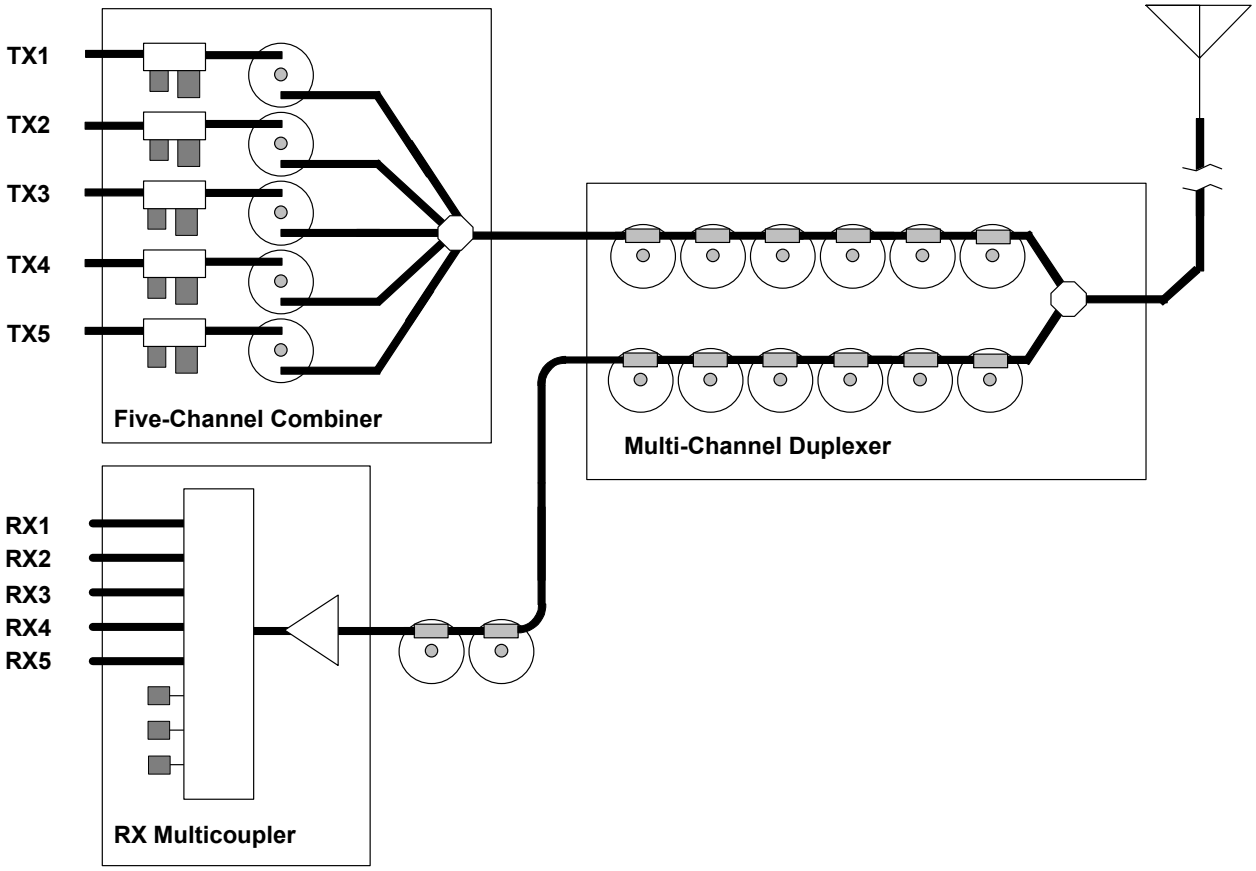

Figure 5.1 Five-Channel Trunked Group Antenna System

5.1.1 Typical Five-channel combiner specifications

Described here is the specification for a five-branch combiner with each branch composed of a dual-stage isolator and a bandpass cavity filter.

Channel spacing:	150 kHz
Isolation:	
antenna-to-TX	>80 dB
TX-to-TX	>90 dB
Insertion loss:	≈ 4 dB
Noise suppression in the rx band (each branch):	>20 dB
Input VSWR:	< 1.2:1

5.1.2 Typical Multi-channel duplexer specifications

Described here is the specification for a multichannel duplexer composed of notch type cavity filters or a combination of notch and bandpass type cavity filters.

For Trunked Group 1: (see Figure 5.2)

Transmitter passband:	220.0-220.6 MHz
Transmitter Noise stopband:	221.0-221.6 MHz
Insertion loss:	< 2.5 dB
Noise Stopband attenuation:	> 85 dB
Input VSWR:	< 1.5:1
Receiver passband:	221.0-221.6 MHz
Transmitter carrier stopband:	220.0-220.6 MHz
RX insertion loss:	< 2.5 dB
Carrier stopband attenuation:	> 85 dB

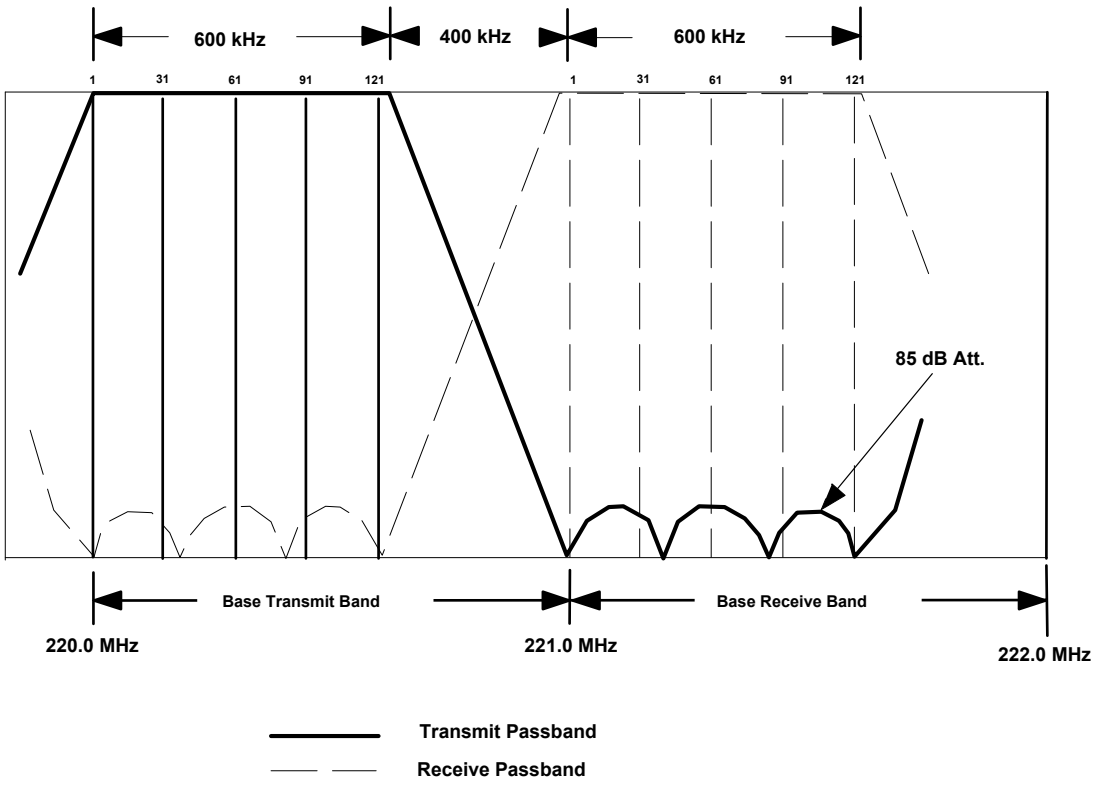

Figure 5.2: Multi-channel Duplexer Characteristic Showing Group 1 Channels

5.1.3 Typical Receiver Multicoupler Specifications

Described here is the specification for a receiver multicoupler with at least five output ports available. This is accomplished using an eight-branch divider with three ports terminated with dummy loads.

Typical gain:	+ 2 dB
Output 3rd order intercept:	> 30 dBm
Noise Figure:	< 4 dB
Isolation between RX ports:	> 20 dB

5.2 ECONOMIC AREA AND REGIONAL AND NATIONWIDE CHANNEL BLOCKS ANTENNA SYSTEM HARDWARE

5.2.1 Introduction

It is important to note that construction of all the assigned EA, Regional or Nationwide license channels, numbering up to fifteen, at any one site may not make sense from a system point of view. For instance, if an F, G, H or I regional licensee wants to blanket a region, one approach would be to construct sites based on an N=3 cellular frequency re-use scheme and acquire

additional channels for high traffic areas as required. If a licensee wishes to construct all channels at the same site, however, special considerations are required. Such cases will require lossy combining systems, special duplexers and/or multiple antennas.

The following cases assume the Phase II licensee is starting system planning and deployment from scratch. Custom designs must be applied to cases where the Phase II licensee is attempting to augment an existing installation (i.e., Phase I) with new channels. Furthermore, since licensees are permitted to disaggregate spectrum, there is the possibility that licensees will swap channels to achieve system and site goals. Fully custom antenna systems will be required in such cases.

5.2.2 EA license systems

For an EA-A or -D license assignment, both trunked groups (2 and 13 or 8 and 19) can be combined using two (2) 5-channel, 150 kHz-spaced cavity combiners with the two combiner outputs ported into a hybrid (see Figure 5.3). The output of the hybrid would then be connected to a duplexer with slightly different specs from those of the 5-channel type used for single trunked groups. The TX passband must be 655 kHz (instead of 600 kHz) and the transition band to TX noise stopband is then reduced to 345 kHz (instead of 400 kHz). At 345 kHz offset, the amount of TX noise suppression required will be about 92 dB for a 100W transmitter.

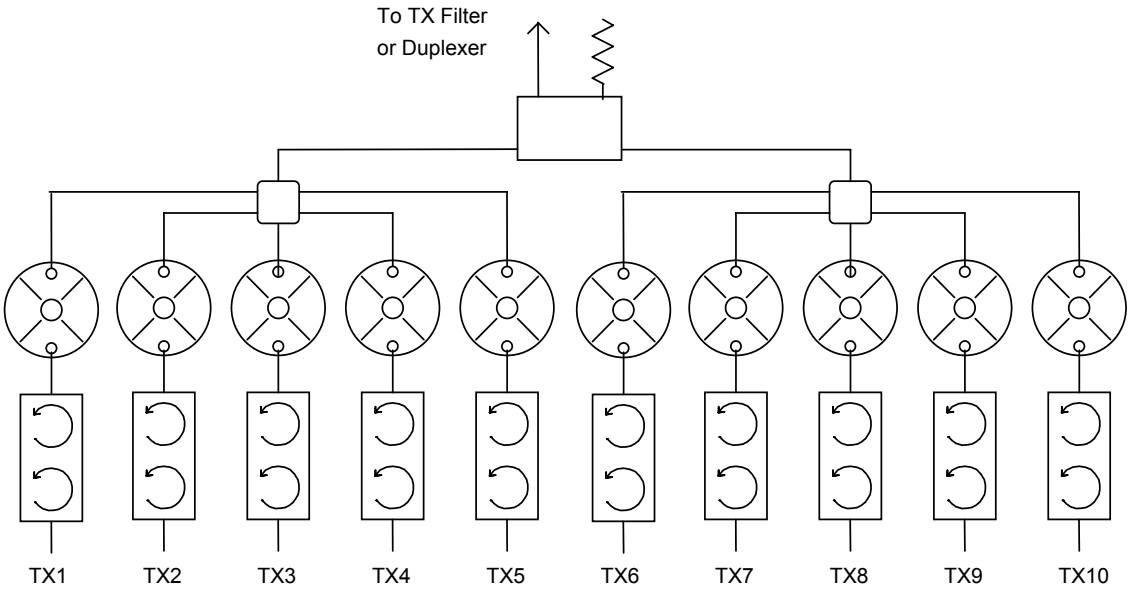

Figure 5.3 10-channel EA license TX combining

The losses for each channel would be approximately as shown below[4].

[4] See Section 5.2.5 for a complete explanation of this and the other accompanying charts.

EA LICENSE TX COMBINER LOSS EXAMPLE (D LICENSE)										
			CHANNEL NUMBER							
Device	**8**	**19**	**38**	**49**	**68**	**79**	**98**	**109**	**128**	**139**
hybrid	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
combiner	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
total loss (dB)	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
PEP in, dBm	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
PEP out, dBm	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4
PEP out, W	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4
Peak V out (Vp)	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5
Sum of Vps (Vpt)	294.8									
Total PEP	1737.8									
Ave. power	54.9									

The same kind of system can be used for an EA-B or -C licensee, except that the TX passband will be 665 kHz and the transition band will be 335 kHz. At a 335 kHz offset, the amount of TX noise suppression required will be about 93 dB for a 100W transmitter.

Tests performed at SEA demonstrate that about 13 dB of noise attenuation (relative to the input) is provided at 335 kHz above the highest TX channel using a Celwave TJO220-5T combiner. An additional 80 dB therefore must be provided by the duplexer. The duplexer must provide at least 80 dB of attenuation over the band 355kHz to 1000kHz above the highest transmit frequency. Such a design would be a general single antenna solution for all noncontiguously-spaced EA licenses, but each such license type (A, B, C or D) would require slightly different tuning.

EA-E channels are contiguously spaced and require hybrid combining and a duplexer with a minimum TX passband of 50 kHz, a nominal transition band of 950 kHz and a minimum stopband of 50 kHz. Total noise suppression in the RX passband should be about 85 dB for 1 MHz. The combiner will provide 10 dB of noise suppression (insertion loss) so the duplexer needs to provide the other 75 dB.

5.2.3 Regional license systems

The F, G, H and I Regional assignments are such that all 15 channels cannot co-exist on a single antenna. Each assignment is composed of three 5-channel Phase 1 channel Groups. A problem exists in that each assignment includes a 5-channel Group whose transmit frequencies create intermodulation distortion products that fall on the receive frequencies of one of the other Groups. For instance, assignment F is composed of channel Groups 1, 6, and 11. The five channels of Group 1 (1, 31, 61, 91 and 121) create intermodulation products that fall on the receiver frequencies of Group 11 (11, 41,71,101 and 131). Also, if Groups 1 and 11 were combined, the system would have channels separated by 50 kHz and 100 kHz, resulting in more mechanisms where intermodulation products could be created. These products would fall on both Group 1 and Group 11 RX channels.

It is possible that all three groups could co-exist at the same site, but the use of dual (TX & RX) antennas seems a certainty. That said, since the lowest frequencies of each five-channel group are within 50 kHz, a five-branch cavity combiner in conjunction with hybrid combining could be used to get all 15 channels into one port. The Figure 5.4 below shows the F assignment case.

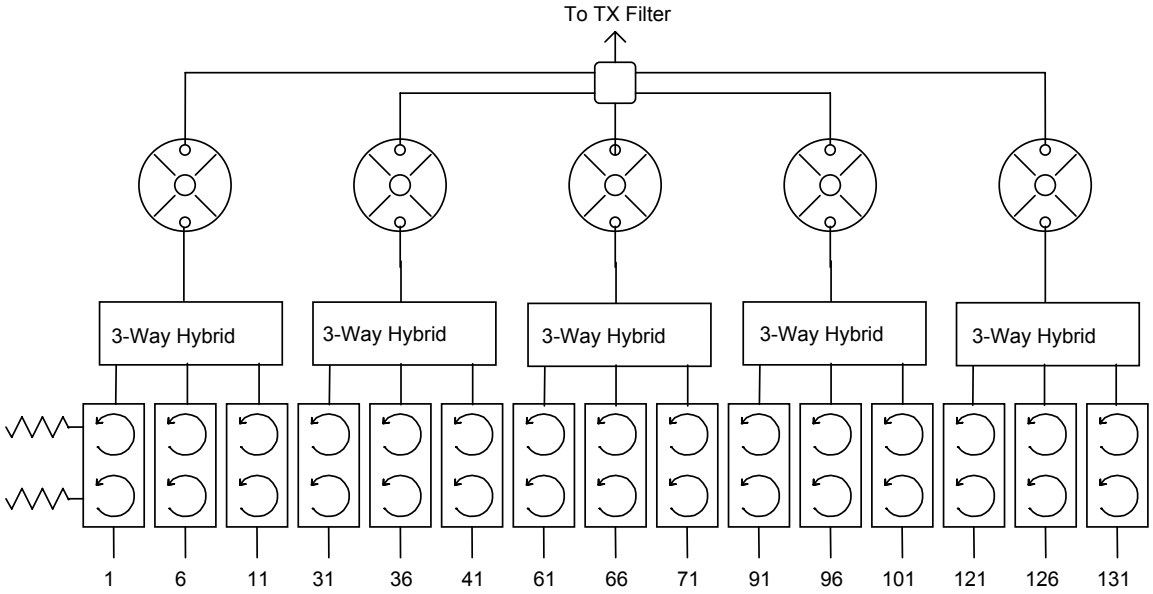

Figure 5.4 15-channel Regional license TX combining

The losses for each channel would be approximately as shown below.

REAG TX COMBINER LOSS EXAMPLE															
	CHANNEL NUMBER														
Device	**1**	**6**	**11**	**31**	**36**	**41**	**61**	**66**	**71**	**91**	**96**	**101**	**121**	**126**	**131**
isolator (dB)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1	1	1	1
combiner (dB)	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
total loss (dB) >	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
PEP in, dBm	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50	50	50	50
PEP out, dBm	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2
PEP out, W	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3
Peak V out (Vp)	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3
Sum of Vps (Vpt)	544.0														
total PEP	5918.1														
ave. power	124.7														

In consideration of the Regional assignment TX filter design, the spread between the highest and lowest transmit frequencies is 650 kHz, the transition band is 350 kHz, and the noise stopband is 650 kHz. At a 350 kHz offset, the companion receiver needs 92 dB of isolation from a 100W transmitter. The combiner cavities provide about 13 dB (including insertion loss). Between vertical antenna spacing and the TX filter stopband it should be easy to provide the additional 79 dB attenuation.

One should not be misled by the numbers posed above. One might conclude from the 79-dB figure that this system could be hooked up to a single antenna via a duplexer. Remember that the combining system and filter described above are providing isolation from noise that is output from a transmitter power amplifier. The intermodulation products that are inherent in the combination of channels can be generated anywhere in the combiner/filter chain, including the connectors in the filter network. It is not possible to predict the levels of such products and it would be difficult to eliminate them under all conditions (time, tarnish, and temperature), so it is best to simply avoid them.

5.2.4 Nationwide license systems

The only solution for combining contiguous channels, no matter how many are to be used at a site, is the use of hybrid combiners. Multiple antennas may be used to reduce losses but for each antenna there would be a filter and transmission line, so a trade-off exists between loss and hardware cost plus tower space. There are many solutions. An example combining system is shown in Figure 5.5 below.

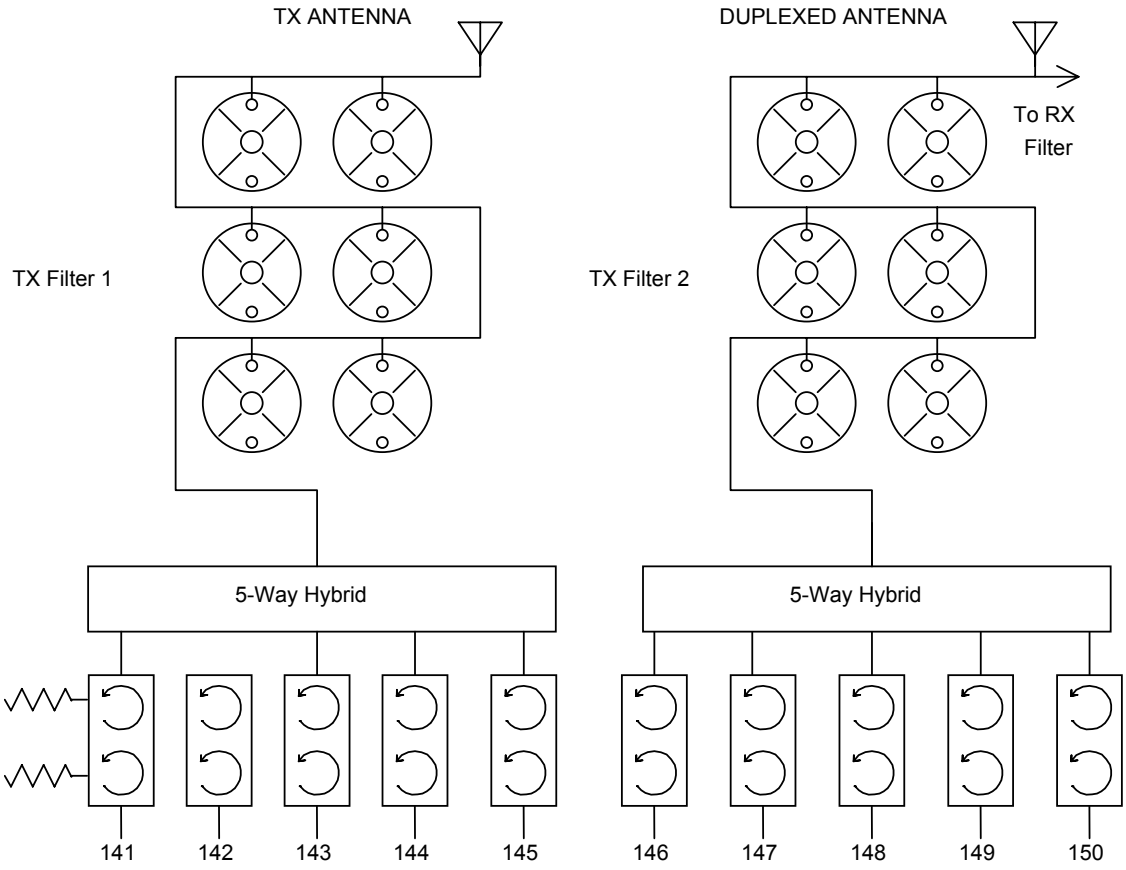

Figure 5.5: Combining 10 contiguously-space channels and associated TX filters

Two five-channel combiners are used to minimize total loss per channel. Two antennas are required for this approach. The losses for each channel would be approximately as shown below.

		NATIONWIDE TX COMBINER LOSS EXAMPLE								
			CHANNEL NUMBERS							
device loss	**141**	**142**	**143**	**144**	**145**	**146**	**147**	**148**	**149**	**150**
isolator (dB)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
five-way hybrid (dB)	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
TX filter (dB)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
total loss (dB) >	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
PEP in, dBm	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
PEP out, dBm	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
PEP out, W	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Peak V out (Vp)	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4
Sum of Vps (Vpt)	223.6									
total PEP	1000.0									
ave. power	31.6									

The multi-channel duplexer for this example is easy to design because channels are contiguous and collectively occupy only 50 kHz of bandwidth. For the nominal 1 MHz T/R split, a minimum 80 dB of TX noise suppression is recommended using a single 100W transmitter. When combining ten transmitter outputs, the TX noise suppression requirements increase an additional 10 dB. The insertion loss of the five channel combiners is about 8.5 dB so 81.5 dB noise suppression must be provided by the TX filter or duplexer over the 50 kHz RX channel band[5]. The RX filter must provide a minimum of 69 dB attenuation of the TX carrier frequencies over the TX channel band.

This example assumes no isolation provided by vertically spacing the duplex antenna from the transmit-only antennas. The stopband requirements of the TX filter only can be reduced by an amount equal to the isolation provided by vertical spacing of the antennas. A single antenna version of the above is feasible but will include an additional 3.5 dB TX insertion loss penalty.

5.2.5 Details regarding loss charts used in section 5.2

[5] The filters should have a 1 dB bandwidth of about 100 kHz to account for temperature drift of the cavities.

	EA LICENSE TX COMBINER LOSS EXAMPLE (D)									
			CHANNEL NUMBER							
device loss	**8**	**19**	**38**	**49**	**68**	**79**	**98**	**109**	**128**	**139**
hybrid (dB)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
combiner (dB)	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
total loss (dB) >	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
PEP in, dBm	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
PEP out, dBm	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4
PEP out, W	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4
Peak V out (Vp)	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5
Sum of Vps (Vpt)	294.8									
Total PEP	1737.8									
Ave. power	54.9									

In the chart above, the loss contribution of each device in the combining system is tabulated (e.g., "hybrid") for each channel. The total loss of the combiner system is calculated for each channel ("total loss"). Subsequent calculations reveal other significant characteristics of the combiner.

"PEP in" is the power input to the combiner for each given channel, expressed in dBm (50 dBm = 100W). Subtracting the loss of the combiner yields "PEP out", also in dBm. PEP out is also shown in watts, as an intermediate calculation to "Vp" which is the peak voltage of each respective channel at the output of the combiner. These voltages add up, so at the combiner output the peak voltage that can occur is the "Sum of the Vps", that is, of all channels. From this number, the "Total PEP" at the output of the combiner is calculated to be $Vpt^2/50$. The average power is calculated by adding up the values of "PEP out" (in watts) for each channel and then reducing that value by 5 dB. The reduction of 5 dB applies because the average power of a narrowband voice-modulated transmitter is approximately 5 dB lower than its peak power.

The "Total PEP" and "average power" figures are useful in a number of ways. In the example above, one can see the tremendous PEP present at the output of the combiner. This does not mean that 1700W is present at the combiner output all the time. In fact, the duty cycle of reaching this peak in the composite envelope may be very low. But, it serves to illustrate the magnitude of the challenge of accomplishing the same results using a highly linear multi-channel high power amplifier. Such a power amplifier would need to be able to reach that peak and its power supply would need to be able to deliver the necessary current.

Note that the actual average power is very low, which means a duplexer with 2.5 dB loss will not have to dissipate much power. Compare the values of peak and average power between the 10- and 15-channel cases and note that as the number of channels increases, the composite peak-to-average ratio increases.

5.3 INDIVIDUAL LOCAL CHANNEL ANTENNA SYSTEM HARDWARE

Individual channel antenna systems are the simplest of the categories described here. These

antenna systems consist of the following elements:

- a narrowband pass/reject duplexer,
- a receiver path bandpass cavity filter,
- a transmitter isolator/bandpass cavity filter set, and
- a single transmission line and antenna.

5.3.1 Typical Single-channel duplexer specifications

Described here is an example of a specification for a single channel duplexer composed of notch type cavity filters or a combination of notch and bandpass type cavity filters.

For Individual Channel Number 171:

Transmitter passband center frequency:	220.8525 MHz
Transmitter Noise notch frequency:	221.8525 MHz
Insertion loss:	< 1.5 dB
Noise Stopband attenuation:	> 80 dB
Input VSWR:	< 1.5:1
Receiver passband center frequency:	221.8525 MHz
Transmitter carrier stopband:	220.8525 MHz
RX insertion loss:	< 1.5 dB
Carrier stopband attenuation:	> 80 dB

5.4 ANTENNA SYSTEM DESIGN CONSIDERATIONS

5.4.1 Combining Multiple Trunked Systems on a Single Antenna

Some trunked group base stations are not compatible with other groups for installation on the same antenna system. This is because worst case intermodulation products (IMs) generated by one group's transmitter antenna system will fall on-frequency with the other's receiver channels. It is prudent to consider this potential interaction when installing any 220 MHz system on a site that already has 220 MHz equipment.

An example of this phenomenon is as follows:

Group 1 base transmitters frequencies are:

Channel	Frequency
1	220.0025
31	220.1525
61	220.3025
91	220.4525
121	220.6025

When these transmitters are combined, filtered (via duplexer) and hooked up to a base station antenna, low-level IM products will be developed by a plethora of mechanisms. In this example, these IM products will fall at 150 kHz increments above channel 121. Affected frequencies would therefore be 220.7525, 220.9025, 221.0525, 221.2025, 221.3525, 221.5025, 221.6525, 221.8025, 221.9525. The underlined above are all Group 11 base receive frequencies. There is the possibility that channels adjacent to the victim channels could be vulnerable as well. The degree of vulnerability might be a function of the ambient noise level at the site. Table 5.1 below summarizes the potential interactions.

Table 5.1 Trunked Group Incompatibility for Sharing Antenna System

RX/TX	1	2	3	4	5	6	7	8	9	10	11	12-20
1-9												
10	?											
11	X	?										
12	?	X	?									
13		?	X	?								
14			?	X	?							
15				?	X	?						
16					?	X	?					
17						?	X	?				
18							?	X	?			
19								?	X	?		
20									?	X	?	

X = intermodulation product hit, ? = possible desense

Another way of expressing the incompatibility relationship is shown in Table 5.2. This table shows the exact base receive channels upon which IM products from each trunked group will fall.

Table 5.2 Trunked Channel IM

Trunked Group Base Transmitters:	Create Intermodulation products that fall on Base Receiver channels:
1	**11,41,71,101,131**,161,191
2	**12,42,72,102,132**,162,192
3	**13,43,73,103,133**,163,193
4	**14,44,74,104,134**,164,194
5	**15,45,75,105,135**,165,195
6	**16,46,76,106,136**,166,196
7	**17,47,77,107,137**,167,197
8	**18,48,78,108,138**,168,198
9	**19,49,79,109,139**,169,199
10	**20,50,80,110,140**,170,200
11	*21,51,81,111,141*,171
12	*22,52,82,112,142*,172
13	*23,53,83,113,143*,173
14	*24,54,84,114,144*,174
15	*25,55,85,115,145*,175
16	*26,56,86,116,146*,176
17	*27,57,87,117,147*,177
18	*28,58,88,118,148*,178
19	*29,59,89,119,149*,179
20	*30,60,90,120,150*,180

Channels shown in bold are other trunked channels. Those shown in Italics are nationwide licensed channels. All others are conventional channels; Public Safety/Mutual Aid, EMRS, unrestricted conventional, and data only conventional.

Note that channels 161 - 200 are in Sub-Band B and therefore will generally be safe from this phenomenon since stations operating on these channels must be geographically separated from Sub-Band A stations (see FCC rules 90.723 (d)). Since each trunked group includes at least one Sub-Band A channel, the conventional stations will generally not be installed at trunked system sites.

For those systems that must co-exist at a given site, vertical separation of trunked group transmit antennas from receive antennas for the above "victim" channels will minimize any potential interference.

5.5 UNUSUAL INTERFERENCE MECHANISMS

5.5.1 72/75 MHz Fixed Operation

One mechanism for interference is intermodulation mixing by fixed remote control channel transmitters in the 72 and 75 MHz bands. Transmitters used in this band may have been in operation for many years without causing problems. In many cases, however, they were placed in operation without proper antenna-to-transmitter isolation and therefore are capable of creating 2A+B spurious mixes. In particular, transmitters operating on frequencies in the 72.54-72.98 MHz band (A) can mix with signals in the range 75.42-75.98 MHz band (B) to create spurious signals in the 221-222 MHz base station receiver band. As an example, when transmitters tuned to 72.90 MHz and 75.50 MHz are co-located, spurious product could be developed at:

$$2*72.90 + 75.50 = 221.30 \text{ MHz}$$

If a 220 MHz repeater with its receiver tuned to 221.3025 MHz (channel 61) is located at the same site, interference to the 220 MHz system could occur. There is a possibility that channels 60 and 62 would be vulnerable, as well.

The solution is to investigate the possible sources of interference prior to installation; don't wait for interference to happen before action is taken. Be proactive. In this case, cleaning up the site and adding isolators to the offending transmitters would be required. Obtaining isolation through antenna positioning can help. Remember: the problem in this case is isolation between the 72 and 75 MHz transmitters.