# AMPS

## Introduction

The first cellular networks used analog FM voice channels. These are the so-called "*first-generation*" (1G) cellular systems. In the US the first-generation system is called AMPS, for Advanced Mobile Phone System. It was deployed in 1983. Although AMPS is being phased out, it is still an important component of the cellular infrastructure. Digital phones that cannot connect to a digital base station, as is often the case in rural settings, typically go into an "analog roaming" mode in which they access the AMPS network.

## Radio Characteristics and Reuse Pattern

AMPS, like AM/FM radio and analog TV broadcasts, uses Frequency Division Multiple Access (FDMA). In FDMA we divide the available bandwidth into multiple frequency intervals to form channels. Each conversation makes use of a particular frequency interval for the entire duration of a call. This is illustrated in Fig. 34.1.

Amps uses 30-kHz-wide analog FM for voice channels, and 30-kHz-wide binary FSK control channels. Base on empirical studies, an *S/I* of 18 dB is considered a minimum for satisfactory performance. Assuming a propagation constant $n = 4$ our formula relating *S/I* to *N* and *n* reads

$$\frac{\left(\sqrt{3N}\right)^4}{6} = 10^{\frac{18}{10}} \tag{10.1}$$

From which we find $N = 6.5$. Therefore, we require an $N = 7$. For smaller values of *n* sectoring might be required to achieve an acceptable *S/I*. Therefore AMPS specifies $N = 7$, but allows either omni cells or 120° sectoring.

Analog FM voice channels are limited to audio frequencies less than 4 kHz. This is similar to the frequency response of traditional cooper-wire analog phone service, referred to as "toll quality." AMPS channels use a frequency deviation of $\Delta f = 12\,\text{kHz}$ giving a frequency modulation index of about $\beta = 3$. The binary FSK control channels use a frequency deviation $\Delta f = 8$ kHz at a bit rate $R_b = 10\,\text{kbps}$. Recall that minimum-shift keying would require $\Delta f = R_b / 4 = 2.5\,\text{kHz}$. Since the deviation used (8 kHz) is considerably more than 2.5 kHz, the spectral efficiency of AMPS control channels is not very good. In fact, it is only 1/3 bps/Hz. However, this enabled reliable demodulation with a less-than-ideal FSK receiver, an important plus more than twenty some years ago when AMPS was being developed.

  

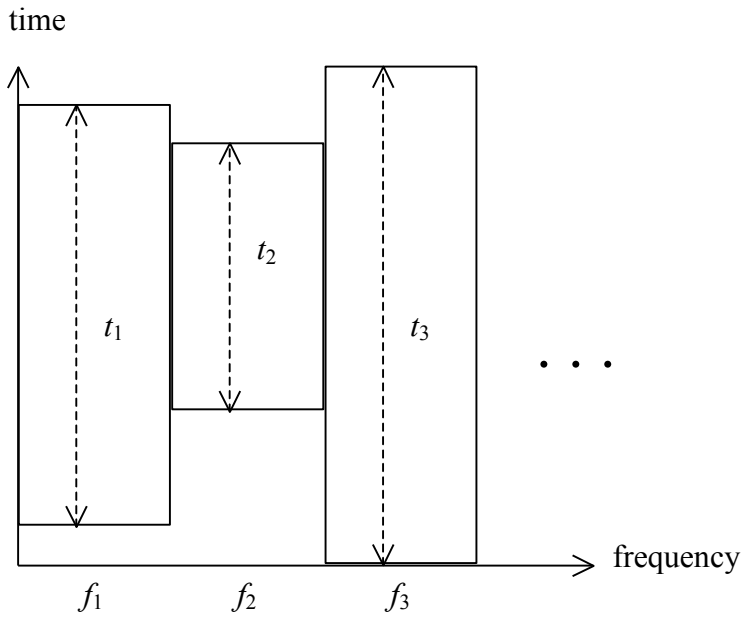


*Figure 34.1: Frequency Division Multiple Access (FDMA). Each call has exclusive use of a particular frequency interval for the duration of the conversation.*

# Frequencies

Originally 40 MHz of spectrum was allocated for the AMPS system with 20 MHz each for uplink and downlink channels. In 1989 an additional 10 MHz was added to meet increased demand. This two-step allocation resulted in a somewhat convoluted labeling and distribution of channels.

AMPS channels have a bandwidth of 30 kHz (0.03 MHz). Each channel is assigned a number $n$ where $1 \le n \le 799$ or $991 \le n \le 1023$. The result is a total of 832 channels covering a bandwidth $832(0.03) = 24.96\,\text{MHz}$. The actual FCC allocation is 25 MHz which allows for some "guard band" to avoid interference with other radio frequencies. Channels are "full duplex," meaning that each $n$ corresponds to two 30-kHz channels, one for the uplink (mobile to base) and one for the downlink (base to mobile). The uplink and downlink frequencies are always 45 MHz apart and are given by

$$f_{n,up}(\text{MHz}) = \begin{cases} 825 + 0.03n & \text{for} \quad 1 \le n \le 799 \\ 825 - 0.03(1023 - n) & \text{for} \quad 991 \le n \le 1023 \end{cases} \qquad (34.1)$$

$$f_{n,down}(\text{MHz}) = f_{n,up} + 45$$

There are no channels 800 through 990.

In order to provide competition in each cellular market, the FCC divides the 832 channels into two blocks of 416 channels. These blocks are assigned to two companies, typically through an FCC spectrum auction. The two companies are referred to as the "A carrier" and the "B carrier." The B carrier is typically the local "wireline" company while the A carrier is typically a

company that does not provide wireline service in the area served. The A carrier uses channels 1-333, 667-716 and 991-1023. The B carrier uses channels 334-666 and 717-799. (As mentioned above, the channel notation and allocation is somewhat confusing.)

AMPS uses an $N = 7$ reuse pattern, with or without 120° sectoring. Accordingly each carrier's 416 channels are arranged into 21 subsets of 19 or 20 channels, as shown in Figs. 34.1 and 34.2.

For $N = 7$ with 120° sectoring, subsets 1A, 1B, and 1C could be used for the three sectors in the first cell, subsets 2A, 2B, and 2C for the three sectors in the second cell, and so on up to 7A, 7B, and 7C. This method insures that channels used within a sector are separated by at least $21 \cdot 30 = 630\,\text{kHz}$, for example, subset 1A uses channels 1, 22, 43, etc. Also, channels in adjacent sectors are separated by at least $7 \cdot 30 = 210\,\text{kHz}$, for example subset 1B uses channels 8, 29, 50, etc. that are 210 kHz separated from the corresponding channels in subset 1A. This frequency separation helps minimize so-called *adjacent-channel interference*. In a radio receiver bandpass filters are used to separate a channel from other channels. Since perfect bandpass filters do not exist, some power from nearby channels may leak into the receiver. If there is a lot of power at frequencies adjacent to the desired channel, this creates adjacent-channel interference. By distributing channels such that no cell or sector uses adjacent channels, this problem is minimized.

Twenty-one of the channels in each block are used for *control channels*: 313-333 for the A carrier and 334-354 for the B carrier. For $N = 7$ with 120° sectoring this allows each sector to have a unique control channel. The result is one control channel and about nineteen voice channels per sector.

Often an $N = 7$ omni reuse pattern is used, that is, sectoring is not implemented. In this case three channel subsets can be used in each cell, for example, 1A+1B+1C could be used in cell 1, 2A+2B+2C could be used in cell 2, and so on. The worst-case *S/I* is of course lower (by about 5 dB) but if traffic is generally light then typically the interference is considerably less than the worst-case scenario. This is often true in rural areas, for example.

However, downlink control channels are always transmitting, so the worst-case scenario always holds for them. On the other hand, since only one control channel is needed per cell and there are twenty-one, three different subsets of seven control channels are available to be assigned to different $N = 7$ clusters. The result is an improved *S/I* on the control channels that somewhat offsets the lack of sectoring. We therefore end up with one control channel, and about 57 voice channels per cell.

| 1A | 2A | 3A | 4A | 5A | 6A | 7A | 1B | 2B | 3B | 4B | 5B | 6B | 7B | 1C | 2C | 3C | 4C | 5C | 6C | 7C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 |
| 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 |
| 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 |
| 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |
| 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 |
| 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 | 138 | 139 | 140 | 141 | 142 | 143 | 144 | 145 | 146 | 147 |
| 148 | 149 | 150 | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 |
| 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 |
| 190 | 191 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 | 201 | 202 | 203 | 204 | 205 | 206 | 207 | 208 | 209 | 210 |
| 211 | 212 | 213 | 214 | 215 | 216 | 217 | 218 | 219 | 220 | 221 | 222 | 223 | 224 | 225 | 226 | 227 | 228 | 229 | 230 | 231 |
| 232 | 233 | 234 | 235 | 236 | 237 | 238 | 239 | 240 | 241 | 242 | 243 | 244 | 245 | 246 | 247 | 248 | 249 | 250 | 251 | 252 |
| 253 | 254 | 255 | 256 | 257 | 258 | 259 | 260 | 261 | 262 | 263 | 264 | 265 | 266 | 267 | 268 | 269 | 270 | 271 | 272 | 273 |
| 274 | 275 | 276 | 277 | 278 | 279 | 280 | 281 | 282 | 283 | 284 | 285 | 286 | 287 | 288 | 289 | 290 | 291 | 292 | 293 | 294 |
| 295 | 296 | 297 | 298 | 299 | 300 | 301 | 302 | 303 | 304 | 305 | 306 | 307 | 308 | 309 | 310 | 311 | 312 | | | |
| **313** | **314** | **315** | **316** | **317** | **318** | **319** | **320** | **321** | **322** | **323** | **324** | **325** | **326** | **327** | **328** | **329** | **330** | **331** | **332** | **333** |
| | | | | | | | | | | | | | | | | | | 667 | 668 | 669 |
| 670 | 671 | 672 | 673 | 674 | 675 | 676 | 677 | 678 | 679 | 680 | 681 | 682 | 683 | 684 | 685 | 686 | 687 | 688 | 689 | 690 |
| 691 | 692 | 693 | 694 | 695 | 696 | 697 | 698 | 699 | 700 | 701 | 702 | 703 | 704 | 705 | 706 | 707 | 708 | 709 | 710 | 711 |
| 712 | 713 | 714 | 715 | 716 | | | | | 991 | 992 | 993 | 994 | 995 | 996 | 997 | 998 | 999 | 1000 | 1001 | 1002 |
| 1003 | 1004 | 1005 | 1006 | 1007 | 1008 | 1009 | 1010 | 1011 | 1012 | 1013 | 1014 | 1015 | 1016 | 1017 | 1018 | 1019 | 1020 | 1021 | 1022 | 1023 |

*Figure 34.1: A-carrier AMPS channel allocation. High-lighted row contains control channels; the rest are voice channels. (After Rappaport.)*

| 1A | 2A | 3A | 4A | 5A | 6A | 7A | 1B | 2B | 3B | 4B | 5B | 6B | 7B | 1C | 2C | 3C | 4C | 5C | 6C | 7C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **334** | **335** | **336** | **337** | **338** | **339** | **340** | **341** | **342** | **343** | **344** | **345** | **346** | **347** | **348** | **349** | **350** | **351** | **352** | **353** | **354** |
| 355 | 356 | 357 | 358 | 359 | 360 | 361 | 362 | 363 | 364 | 365 | 366 | 367 | 368 | 369 | 370 | 371 | 372 | 373 | 374 | 375 |
| 376 | 377 | 378 | 379 | 380 | 381 | 382 | 383 | 384 | 385 | 386 | 387 | 388 | 389 | 390 | 391 | 392 | 393 | 394 | 395 | 396 |
| 397 | 398 | 399 | 400 | 401 | 402 | 403 | 404 | 405 | 406 | 407 | 408 | 409 | 410 | 411 | 412 | 413 | 414 | 415 | 416 | 417 |
| 418 | 419 | 420 | 421 | 422 | 423 | 424 | 425 | 426 | 427 | 428 | 429 | 430 | 431 | 432 | 433 | 434 | 435 | 436 | 437 | 438 |
| 439 | 440 | 441 | 442 | 443 | 444 | 445 | 446 | 447 | 448 | 449 | 450 | 451 | 452 | 453 | 454 | 455 | 456 | 457 | 458 | 459 |
| 460 | 461 | 462 | 463 | 464 | 465 | 466 | 467 | 468 | 469 | 470 | 471 | 472 | 473 | 474 | 475 | 476 | 477 | 478 | 479 | 480 |
| 481 | 482 | 483 | 484 | 485 | 486 | 487 | 488 | 489 | 490 | 491 | 492 | 493 | 494 | 495 | 496 | 497 | 498 | 499 | 500 | 501 |
| 502 | 503 | 504 | 505 | 506 | 507 | 508 | 509 | 510 | 511 | 512 | 513 | 514 | 515 | 516 | 517 | 518 | 519 | 520 | 521 | 522 |
| 523 | 524 | 525 | 526 | 527 | 528 | 529 | 530 | 531 | 532 | 533 | 534 | 535 | 536 | 537 | 538 | 539 | 540 | 541 | 542 | 543 |
| 544 | 545 | 546 | 547 | 548 | 549 | 550 | 551 | 552 | 553 | 554 | 555 | 556 | 557 | 558 | 559 | 560 | 561 | 562 | 563 | 564 |
| 565 | 566 | 567 | 568 | 569 | 570 | 571 | 572 | 573 | 574 | 575 | 576 | 577 | 578 | 579 | 580 | 581 | 582 | 583 | 584 | 585 |
| 586 | 587 | 588 | 589 | 590 | 591 | 592 | 593 | 594 | 595 | 596 | 597 | 598 | 599 | 600 | 601 | 602 | 603 | 604 | 605 | 606 |
| 607 | 608 | 609 | 610 | 611 | 612 | 613 | 614 | 615 | 616 | 617 | 618 | 619 | 620 | 621 | 622 | 623 | 624 | 625 | 626 | 627 |
| 628 | 629 | 630 | 631 | 632 | 633 | 634 | 635 | 636 | 637 | 638 | 639 | 640 | 641 | 642 | 643 | 644 | 645 | 646 | 647 | 648 |
| 649 | 650 | 651 | 652 | 653 | 654 | 655 | 656 | 657 | 658 | 659 | 660 | 661 | 662 | 663 | 664 | 665 | 666 | | | |
| | | | | | 717 | 718 | 719 | 720 | 721 | 722 | 723 | 724 | 725 | 726 | 727 | 728 | 729 | 730 | 731 | 732 |
| 733 | 734 | 735 | 736 | 737 | 738 | 739 | 740 | 741 | 742 | 743 | 744 | 745 | 746 | 747 | 748 | 749 | 750 | 751 | 752 | 753 |
| 754 | 755 | 756 | 757 | 758 | 759 | 760 | 761 | 762 | 763 | 764 | 765 | 766 | 767 | 768 | 769 | 770 | 771 | 772 | 773 | 774 |
| 775 | 776 | 777 | 778 | 779 | 780 | 781 | 782 | 783 | 784 | 785 | 786 | 787 | 788 | 789 | 790 | 791 | 792 | 793 | 794 | 795 |
| 796 | 797 | 798 | 799 | | | | | | | | | | | | | | | | | |

*Figure 34.2: B-carrier AMPS channel allocation. High-lighted row contains control channels; the rest are voice channels. (After Rappaport.)*

## System Capacity

An AMPS system with $N = 7$ and 120° sectoring provides about 19 channels per sector. For a PB (GOS) of 2% this gives an offered traffic intensity of 12.33 Erlangs/sector, and about 36 Erlangs of carried traffic per cell. For the omni case, we have about 57 voice channels, and this gives about 46 Erlangs of carried traffic per cell.

AMPS cells can have radii of upwards of 32 km (20 mi). Due to limited mobile transmit power, this can be problematic for the uplink. Accordingly two-antenna diversity reception is typically employed at base stations.

## References

1. Rappaport, T. S., *Wireless Communications: Principles and Practice*, Prentice Hall, 1996, ISBN 0-13-375536-3.

  