

U.S. PATENT DOCUMENTS

4,625,289 A	11/1986	Rockwood	5,416,606 A	5/1995	Katayama et al.
4,653,012 A	3/1987	Duffy et al.	5,421,028 A	5/1995	Swanson
4,658,247 A	4/1987	Gharachorloo	5,422,997 A	6/1995	Nagashima
4,692,880 A	9/1987	Merz et al.	5,432,895 A	7/1995	Myers
4,695,943 A	9/1987	Keeley et al.	5,432,900 A	7/1995	Rhodes et al.
4,710,876 A	12/1987	Cline et al.	5,438,663 A	8/1995	Matsumoto et al.
4,725,831 A	2/1988	Coleman	5,448,689 A	9/1995	Matsuo et al.
4,768,148 A	8/1988	Keeley et al.	5,457,775 A	10/1995	Johnson, Jr. et al.
4,785,395 A	11/1988	Keeley	5,461,712 A	10/1995	Chelstowski et al.
4,790,025 A	12/1988	Inoue et al.	5,467,438 A	11/1995	Nishio et al.
4,808,988 A	2/1989	Burke et al.	5,467,459 A	11/1995	Alexander et al.
4,812,988 A	3/1989	Duthuit et al.	5,469,535 A	11/1995	Jarvis et al.
4,817,175 A	3/1989	Tenenbaum et al.	5,473,736 A	12/1995	Young
4,829,295 A	5/1989	Hiroyuki	5,475,803 A	12/1995	Stearns et al.
4,829,452 A	5/1989	Kang et al.	5,487,146 A	1/1996	Guttag et al.
4,833,601 A	5/1989	Barlow et al.	5,490,240 A	2/1996	Foran et al.
4,855,934 A	8/1989	Robinson	5,495,563 A	2/1996	Winser
4,862,392 A	8/1989	Steiner	5,504,499 A	4/1996	Horie et al.
4,866,637 A	9/1989	Gonzalez-Lopez et al.	5,504,917 A	4/1996	Austin
4,888,712 A	12/1989	Barkans et al.	5,506,604 A	4/1996	Nally et al.
4,897,806 A	1/1990	Cook et al.	5,535,374 A	7/1996	Olive
4,901,064 A	2/1990	Deering	5,543,824 A	8/1996	Priem et al.
4,907,174 A	3/1990	Priem	5,544,292 A	8/1996	Winser
4,914,729 A	4/1990	Omori et al.	5,548,709 A	8/1996	Hannah et al.
4,918,625 A	4/1990	Yan	5,553,228 A	9/1996	Erb et al.
4,935,879 A	6/1990	Ueda	5,557,712 A	9/1996	Guay
4,945,500 A	7/1990	Deering	5,559,954 A	9/1996	Sakoda et al.
4,965,751 A	10/1990	Thayer et al.	5,561,746 A	10/1996	Murata et al.
4,974,176 A	11/1990	Buchner et al.	5,561,752 A	10/1996	Jevans
4,974,177 A	11/1990	Nishiguchi	5,563,989 A	10/1996	Billyard
4,975,977 A	12/1990	Kurosu et al.	5,566,285 A	10/1996	Okada
4,989,138 A	1/1991	Radochonski	5,573,402 A	11/1996	Gray
5,003,496 A	3/1991	Hunt, Jr. et al.	5,579,456 A	11/1996	Cosman
5,016,183 A	5/1991	Shyong	5,586,234 A	12/1996	Sakuraba et al.
5,018,076 A	5/1991	Johary et al.	5,593,350 A *	1/1997	Bouton et al. 273/148 B
5,043,922 A	8/1991	Matsumoto	5,594,854 A	1/1997	Baldwin et al.
5,056,044 A	10/1991	Frederickson et al.	5,600,763 A	2/1997	Greene et al.
5,062,057 A	10/1991	Blacken et al.	5,606,650 A	2/1997	Kelley et al.
5,086,495 A	2/1992	Gray et al.	5,607,157 A	3/1997	Nagashima 273/148
5,091,967 A	2/1992	Ohsawa	5,608,424 A	3/1997	Takahashi et al.
5,097,427 A	3/1992	Lathrop et al.	5,608,864 A	3/1997	Bindlish et al.
5,136,664 A	8/1992	Bersack et al.	5,616,031 A	4/1997	Logg
5,144,291 A	9/1992	Nishizawa	5,621,867 A	4/1997	Murata et al.
5,163,126 A	11/1992	Einkauf et al.	5,628,686 A *	5/1997	Svancarek et al. 463/36
5,170,468 A	12/1992	Shah et al.	5,638,535 A *	6/1997	Rosenthal et al. 710/1
5,179,638 A	1/1993	Dawson et al.	5,644,364 A	7/1997	Kurtze et al.
5,204,944 A	4/1993	Wolberg et al.	5,649,082 A	7/1997	Burns
5,224,208 A	6/1993	Miller, Jr. et al.	5,650,955 A	7/1997	Puar et al.
5,239,624 A	8/1993	Cook et al.	5,651,104 A	7/1997	Cosman
5,241,658 A	8/1993	Masterson et al.	5,657,045 A	8/1997	Katsura et al.
5,255,353 A	10/1993	Itoh	5,657,443 A	8/1997	Krech, Jr.
5,268,995 A	12/1993	Diefendorff et al.	5,657,478 A	8/1997	Recker et al.
5,268,996 A	12/1993	Steiner et al.	5,659,671 A	8/1997	Tannenbaum et al.
5,278,948 A	1/1994	Luken, Jr.	5,659,673 A	8/1997	Nonoshita
5,307,450 A	4/1994	Grossman	5,659,715 A	8/1997	Wu et al.
5,315,692 A	5/1994	Hansen et al.	5,664,162 A	9/1997	Dye
5,345,541 A	9/1994	Kelley et al.	5,666,439 A	9/1997	Ishida et al.
5,353,424 A	10/1994	Partovi et al.	5,678,037 A	10/1997	Osugi et al.
5,357,579 A	10/1994	Buchner et al.	5,682,522 A	10/1997	Huang et al.
5,361,386 A	11/1994	Watkins et al.	5,684,941 A	11/1997	Dye
5,363,475 A	11/1994	Baker et al.	5,687,304 A	11/1997	Kiss
5,377,313 A	12/1994	Scheibl	5,687,357 A	11/1997	Priem
5,392,385 A	2/1995	Evangelisti et al.	5,691,746 A	11/1997	Shyu
5,392,393 A	2/1995	Deering	5,694,143 A	12/1997	Fielder et al.
5,394,516 A	2/1995	Winser	5,696,892 A	12/1997	Redmann et al.
5,402,532 A	3/1995	Epstein et al.	5,701,444 A	12/1997	Baldwin
5,404,445 A	4/1995	Matsumoto	5,703,806 A	12/1997	Puar et al.
5,408,650 A	4/1995	Arsenault	5,706,481 A	1/1998	Hannah et al.
5,412,796 A	5/1995	Olive	5,706,482 A	1/1998	Matsushima et al.
5,415,549 A	5/1995	Logg	5,714,981 A	2/1998	Scott-Jackson et al. 345/161
			5,721,947 A	2/1998	Priem et al.

US 6,811,489 B1

Page 3

5,724,561 A	3/1998	Tarolli et al.	5,870,098 A	2/1999	Gardiner
5,726,689 A	3/1998	Negishi et al.	5,870,102 A	2/1999	Tarolli et al.
5,726,947 A	3/1998	Yamazaki et al.	5,870,109 A	2/1999	McCormack et al.
5,727,192 A	3/1998	Baldwin	5,870,587 A	2/1999	Danforth et al.
5,734,386 A	3/1998	Cosman	5,872,902 A	2/1999	Kuchkuda et al.
5,739,819 A	4/1998	Bar-Nahum	5,874,969 A	2/1999	Storm et al.
5,740,343 A	4/1998	Tarolli et al.	5,877,741 A	3/1999	Chee et al.
5,740,383 A	4/1998	Nally et al.	5,877,770 A	3/1999	Hanaoka
5,740,406 A	4/1998	Rosenthal et al.	5,877,771 A	3/1999	Drebin et al.
5,742,749 A	4/1998	Foran et al.	5,880,736 A	3/1999	Peercy et al.
5,742,788 A	4/1998	Priem et al.	5,880,737 A	3/1999	Griffin et al.
5,745,118 A	4/1998	Alcorn et al.	5,883,638 A	3/1999	Rouet et al.
5,745,125 A	4/1998	Deering et al.	5,886,701 A	3/1999	Chauvin et al.
5,748,199 A	5/1998	Palm	5,886,705 A	3/1999	Lentz
5,748,986 A	5/1998	Butterfield et al.	5,887,155 A	3/1999	Laidig
5,751,291 A	5/1998	Olsen et al.	5,890,190 A	3/1999	Rutman
5,751,292 A	5/1998	Emmot	5,892,517 A	4/1999	Rich
5,751,295 A	5/1998	Becklund et al.	5,892,974 A	4/1999	Koizumi et al. 395/836
5,751,930 A	5/1998	Katsura et al.	5,894,300 A	4/1999	Takizawa
5,754,191 A	5/1998	Mills et al.	5,900,881 A	5/1999	Ikedo
5,757,382 A	5/1998	Lee	5,903,283 A	5/1999	Selwan et al.
5,758,182 A	5/1998	Rosenthal et al.	5,909,218 A	6/1999	Naka et al.
5,760,783 A	6/1998	Migdal et al.	5,909,225 A	6/1999	Schinnerer et al.
5,764,228 A	6/1998	Baldwin	5,912,675 A	6/1999	Laperriere
5,764,237 A	6/1998	Kaneko	5,912,676 A	6/1999	Malladi et al.
5,764,243 A	6/1998	Baldwin	5,914,721 A	6/1999	Lim
5,767,856 A	6/1998	Peterson et al.	5,914,725 A	6/1999	MacInnis et al.
5,767,858 A	6/1998	Kawase et al.	5,914,729 A	6/1999	Lippincott
5,768,626 A	6/1998	Munson et al.	5,917,496 A	6/1999	Fujita et al.
5,768,629 A	6/1998	Wise et al.	5,920,326 A	7/1999	Rentschler et al.
5,774,133 A	6/1998	Neave et al.	5,920,876 A	7/1999	Ungar et al.
5,777,623 A	7/1998	Small	5,923,332 A	7/1999	Izawa
5,777,629 A	7/1998	Baldwin	5,923,334 A	7/1999	Luken
5,781,927 A	7/1998	Wu et al.	5,926,182 A	7/1999	Menon et al.
5,791,994 A	8/1998	Hirano et al. 463/43	5,926,647 A	7/1999	Adams et al.
5,798,770 A	8/1998	Baldwin	5,933,150 A	8/1999	Ngo et al.
5,801,706 A	9/1998	Fujita et al.	5,933,154 A	8/1999	Howard et al.
5,801,711 A	9/1998	Koss et al.	5,933,155 A	8/1999	Akeley
5,801,716 A	9/1998	Silverbrook	5,933,529 A	8/1999	Kim
5,801,720 A	9/1998	Norrod et al.	5,936,641 A	8/1999	Jain et al.
5,805,175 A	9/1998	Priem	5,936,683 A	8/1999	Lin
5,805,868 A	9/1998	Murphy	5,940,086 A	8/1999	Rentschler et al.
5,808,619 A	9/1998	Choi et al.	5,940,089 A	8/1999	Dilliplane
5,808,630 A	9/1998	Pannell	5,940,538 A	8/1999	Spiegel et al.
5,809,219 A	9/1998	Pearce et al.	5,943,058 A	8/1999	Nagy
5,809,278 A	9/1998	Watanabe et al.	5,943,060 A	8/1999	Cosman et al.
5,815,165 A	9/1998	Blixt	5,945,997 A	8/1999	Zhao et al.
5,815,166 A	9/1998	Baldwin	5,949,421 A	9/1999	Ogletree et al.
5,818,456 A	10/1998	Cosman et al.	5,949,423 A	9/1999	Olsen
5,819,017 A	10/1998	Akeley et al.	5,949,424 A	9/1999	Cabral et al.
5,821,940 A	10/1998	Morgan et al.	5,949,428 A	9/1999	Toelle et al.
5,821,949 A	10/1998	Deering	5,949,440 A	9/1999	Krech, Jr. et al.
5,822,516 A	10/1998	Krech, Jr.	5,956,042 A	9/1999	Tucker et al.
5,828,382 A	10/1998	Wilde	5,956,043 A	9/1999	Jensen
5,828,383 A	10/1998	May et al.	5,958,020 A	9/1999	Evoy et al. 710/3
5,828,907 A	10/1998	Wise et al.	5,959,640 A	9/1999	Rudin et al.
5,831,624 A	11/1998	Tarolli et al.	5,963,220 A	10/1999	Lee et al.
5,831,625 A	11/1998	Rich et al.	5,966,134 A	10/1999	Arias
5,831,640 A	11/1998	Wang et al.	5,969,726 A	10/1999	Rentschler et al.
5,835,096 A	11/1998	Baldwin	5,977,979 A	11/1999	Clough et al.
5,835,792 A	11/1998	Wise et al.	5,977,984 A	11/1999	Omori
5,838,334 A	11/1998	Dye	5,982,376 A	11/1999	Abe et al.
5,844,576 A	12/1998	Wilde et al.	5,982,390 A	11/1999	Stoneking et al.
5,850,229 A	12/1998	Edelsbrunner et al.	5,986,659 A	11/1999	Gallery et al.
5,852,451 A	12/1998	Cox et al.	5,986,663 A	11/1999	Wilde
5,856,829 A	1/1999	Gray, III et al.	5,986,677 A	11/1999	Jones et al.
5,859,645 A	1/1999	Latham	5,987,567 A	11/1999	Rivard et al.
5,861,888 A	1/1999	Dempsey	5,990,903 A	11/1999	Donovan
5,861,893 A	1/1999	Sturgess	5,995,120 A	11/1999	Dye
5,867,166 A	2/1999	Myhrvold et al.	5,995,121 A	11/1999	Alcorn et al.
5,870,097 A	2/1999	Snyder et al.	5,999,189 A	12/1999	Kajiya et al.

US 6,811,489 B1

Page 4

5,999,196 A	12/1999	Storm et al.	6,088,701 A	7/2000	Whaley et al.
5,999,198 A	12/1999	Horan et al.	6,091,431 A	7/2000	Saxena et al.
6,002,407 A	12/1999	Fadden	6,092,124 A	7/2000	Priem et al.
6,002,409 A	12/1999	Harkin	6,092,158 A	7/2000	Harriman et al.
6,002,410 A	12/1999	Battle	6,094,200 A	7/2000	Olsen et al.
6,005,582 A	12/1999	Gabriel et al.	6,097,435 A	8/2000	Stanger et al.
6,005,583 A	12/1999	Morrison	6,097,437 A	8/2000	Hwang
6,005,584 A	12/1999	Kitamura et al.	6,104,415 A	8/2000	Gossett
6,007,428 A *	12/1999	Nishiumi et al. 463/36	6,104,417 A	8/2000	Nielsen et al.
6,008,820 A	12/1999	Chauvin et al.	6,105,094 A	8/2000	Lindeman
6,011,562 A	1/2000	Gagne et al.	6,108,743 A	8/2000	Debs et al.
6,011,565 A	1/2000	Kuo et al.	6,111,582 A	8/2000	Jenkins
6,014,144 A	1/2000	Nelson et al.	6,111,584 A	8/2000	Murphy
6,016,150 A	1/2000	Lengyel et al.	6,115,047 A	9/2000	Deering
6,016,151 A	1/2000	Lin	6,115,049 A	9/2000	Winner et al.
6,018,350 A	1/2000	Lee et al.	6,118,462 A	9/2000	Margulis
6,020,931 A	2/2000	Bilbrey et al.	6,128,026 A	10/2000	Brothers, III
6,021,417 A	2/2000	Massarksy	6,144,365 A	11/2000	Young et al.
6,022,274 A	2/2000	Takeda et al. 463/44	6,144,387 A	11/2000	Liu et al.
6,023,261 A	2/2000	Ugajin	6,151,602 A	11/2000	Hejlsberg et al.
6,023,738 A	2/2000	Priem et al.	6,155,926 A	12/2000	Miyamoto et al. 463/32
6,025,853 A	2/2000	Baldwin	6,157,387 A	12/2000	Kotani
6,026,182 A	2/2000	Lee et al.	6,166,748 A	12/2000	Van Hook et al. 345/522
6,028,608 A	2/2000	Jenkins	6,172,678 B1	1/2001	Shiraishi
6,028,611 A	2/2000	Anderson et al.	6,173,367 B1	1/2001	Aleksic et al.
6,031,542 A	2/2000	Wittig	6,177,944 B1	1/2001	Fowler et al.
6,035,360 A	3/2000	Doidge et al.	6,181,352 B1	1/2001	Kirk et al.
6,037,948 A	3/2000	Liepa	6,191,794 B1	2/2001	Priem et al.
6,037,949 A	3/2000	DeRose et al.	6,198,488 B1	3/2001	Lindholm et al.
6,038,031 A	3/2000	Murphy	6,200,253 B1 *	3/2001	Nishiumi et al. 463/47
6,038,348 A	3/2000	Carley	6,204,851 B1	3/2001	Netschke et al.
6,040,843 A	3/2000	Monroe et al.	6,215,496 B1	4/2001	Szeliski et al.
6,040,844 A	3/2000	Yamaguchi et al.	6,215,497 B1	4/2001	Leung
6,041,010 A	3/2000	Puar et al.	6,226,012 B1	5/2001	Priem et al.
6,043,804 A	3/2000	Greene	6,226,713 B1	5/2001	Mehrotra
6,043,821 A	3/2000	Sprague et al.	6,232,981 B1	5/2001	Gossett
6,046,746 A	4/2000	Deering	6,236,413 B1	5/2001	Gossett et al.
6,046,747 A	4/2000	Saunders et al.	6,239,810 B1	5/2001	Van Hook et al. 345/431
6,046,752 A	4/2000	Kirkland et al.	6,252,608 B1	6/2001	Snyder et al.
6,049,337 A	4/2000	Van Overveld	6,252,610 B1	6/2001	Hussain
6,049,338 A	4/2000	Anderson et al.	6,264,558 B1 *	7/2001	Nishiumi et al. 463/36
6,052,125 A	4/2000	Gardiner et al.	6,268,861 B1	7/2001	Sanz-Pastor et al.
6,052,126 A	4/2000	Sakuraba et al.	6,275,235 B1	8/2001	Morgan, III
6,052,127 A	4/2000	Vaswani et al.	6,285,779 B1	9/2001	Lapidous et al.
6,052,129 A	4/2000	Fowler et al.	6,292,194 B1	9/2001	Powell, III
6,052,133 A	4/2000	Kang	6,329,997 B1	12/2001	We et al.
6,054,993 A	4/2000	Devic et al.	6,331,856 B1	12/2001	Van Hook et al. 345/503
6,054,999 A	4/2000	Strandberg	6,339,428 B1	1/2002	Fowler et al.
6,057,847 A	5/2000	Jenkins	6,342,892 B1	1/2002	Van Hook et al. 345/503
6,057,849 A	5/2000	Haubner et al.	6,353,438 B1	3/2002	Van Hook
6,057,851 A	5/2000	Luken et al.	6,356,497 B1	3/2002	Puar et al.
6,057,852 A	5/2000	Krech, Jr.	6,408,362 B1	6/2002	Arimilli et al.
6,057,859 A	5/2000	Handelman et al.	6,417,858 B1	7/2002	Bosch et al.
6,057,861 A	5/2000	Lee et al.	6,426,747 B1	7/2002	Hoppe et al.
6,057,862 A	5/2000	Margulis	6,437,781 B1	8/2002	Tucker et al.
6,057,863 A	5/2000	Olarig	6,459,429 B1	10/2002	Deering
6,061,462 A	5/2000	Tostevin et al.	6,466,223 B1	10/2002	Dorbie et al.
6,064,392 A	5/2000	Rohner	6,469,707 B1	10/2002	Voorhies
6,067,098 A	5/2000	Dye	6,476,808 B1	11/2002	Kuo et al.
6,070,204 A *	5/2000	Poisner 707/101	6,476,822 B1	11/2002	Burbank
6,072,496 A	6/2000	Guenther et al.	6,496,187 B1	12/2002	Deering et al.
6,075,543 A	6/2000	Akeley			
6,075,546 A	6/2000	Hussain et al.			
6,078,311 A *	6/2000	Pelkey 345/161			
6,078,333 A	6/2000	Wittig et al.			
6,078,334 A	6/2000	Hanaoka et al.			
6,078,338 A	6/2000	Horan et al.			
6,081,274 A	6/2000	Shiraishi			
6,088,035 A	7/2000	Sudarsky et al.			
6,088,042 A	7/2000	Handelman et al.			
6,088,487 A	7/2000	Kurashige			

FOREIGN PATENT DOCUMENTS

JP	11161819	6/1999
JP	11203500	7/1999
JP	11226257	8/1999
JP	1125971	9/1999
JP	11259678	9/1999
JP	2000-66985	3/2000
JP	2000-92390	3/2000
JP	2000-132704	5/2000

JP	2000-132706	5/2000
JP	2000-149053	5/2000
JP	200-182077	6/2000
JP	2000-156875	6/2000
JP	2000-207582	7/2000
JP	2000-215325	8/2000
WO	WO/93/04429	3/1993
WO	WO 94/10641	5/1994
WO	WO 94/10641	11/1994

OTHER PUBLICATIONS

White paper, Rogers, Douglas H., "Optimizing Direct3D for the GeForce 256" (Jan. 3, 2000).

Thompson, Tom, "Must-See 3-D Engines," Byte Magazine, printed from web site www.byte.com, 10 pages (Jun. 1996).
Thompson, Nigel, "Rendering with Immediate Mode," Microsoft Interactive Developer Column: Fun and Games, printed from web site msdn.microsoft.com, 8 pages (Mar. 1997).

"HOWTO: Animate Textures in Direct3D Immediate Mode," printed from web site support.microsoft.com, 3 pages (last reviewed Dec. 15, 2000).

INFO: Rendering a Triangle Using an Execute Buffer, printed from web site support.microsoft.com, 6 pages (last reviewed Oct. 20, 2000).

U.S. application Ser. No. 09/337,293, filed Jun. 21, 1999, Multi-Formate Vertex Data Processing Apparatus and Method [issued as U.S. Patent No. 6,501,479 B1 on Dec. 31, 2002].

Datasheet, SGS-Thomson Microelectronics, nVIDIA™, RIVA 128™ 128-Bit 3D Multimedia Accelerator (Oct. 1997).

ZDNet Reviews, from PC Magazine, "Other Enhancements," Jan. 15, 1999, [wysiwyg://16/http://www4.zdnet.com/...ies/reviews/0,4161,2188286,00.html](http://www4.zdnet.com/...ies/reviews/0,4161,2188286,00.html).
ZDNet Reviews, from PC Magazine, "Screen Shot of Alpha-channel Transparency," Jan. 15, 1999, [wysiwyg://16/http://www4.zdnet.com/...ies/reviews/0,4161,2188286,00.html](http://www4.zdnet.com/...ies/reviews/0,4161,2188286,00.html).

Blythe, David, 5.6 Transparency Mapping and Trimming with Alpha, <http://toolbox.sgi.com/TasteOfDT/d...penGL/advanced98/notes/node41.html>, Jun. 11, 1998.

Winner, Stephanie, et al., "Hardware Accelerated Rendering Of Antialiasing Using A Modified A-buffer Algorithm," Computer Graphics Proceedings, Annual Conference Series, 1997, pp. 307-316.

Gibson, Simon, et al., "Interactive Rendering with Real-World Illumination," Rendering Techniques 2000; 11th Eurographics Workshop on Rendering, pp. 365-376 (Jun. 2000).

Segal, Mark, et al., "Fast Shadows and Lighting Effects Using Texture Mapping," Computer Graphics, 26, 2, pp. 249-252 (Jul. 1992).

White paper, Kilgard, Mark J., "Improving Shadows and Reflections via the Stencil Buffer" (Nov. 3, 1999).

Arkin, Alan, email, subject: "Texture distortion problem," from web site: [HTTP://reality.sgi.com](http://reality.sgi.com) (Jul. 1997).

Moller, Tomas et al., "Real-Time Rendering," pp. 179-183 (AK Peters Ltd., 1999).

Williams, Lance, "Casting Curved Shadows on Curved Surfaces," Computer Graphics (SIGGRAPH '78 Proceedings), vol. 12, No. 3, pp. 270-274 (Aug. 1978).

Woo et al., "A Survey of Shadow Algorithms," IEEE Computer Graphics and Applications, vol. 10, No. 6, pp. 13-32 (Nov. 1990).

Heidrich et al., "Applications of Pixel Textures in Visualization and Realistic Image Synthesis," Proceedings 1999 Symposium On Interactive 3D Graphics, pp. 127-134 (Apr. 1999).

Hourcade et al., "Algorithms for Antialiased Cast Shadows," Computers and Graphics, vol. 9, No. 3, pp. 260-265 (1985).

Michael McCool, "Shadow Volume Reconstruction from Depth Maps", ACM Transactions on Graphics, vol. 19, No. 1, Jan. 2000, pp. 1-26.

RenderMan Artist Tools, PhotoRealistic RenderMan 3.8 User's Manual, Pixar (Aug. 1998).

RenderMan Interface Version 3.2 (Jul. 2000).

White paper, Dietrich, Sim, "Cartoon Rendering and Advanced Texture Features of the GeForce 256 Texture Matrix, Projective Textures, Cube Maps, Texture Coordinate Generation and DOTPRODUCT3 Texture Blending" (Dec. 16, 1999).

Peter J. Kovach, Inside Direct 3D, "Alpha Testing," pp. 289-291 (1999).

Raskar, Ramesh et al., "Image Precision Silhouette Edges," Symposium on Interactive 3D Graphics 1999, Atlanta, 7 pages (Apr. 26-29, 1999).

Schlechtweg, Stefan et al., Rendering Line-Drawings with Limited Resources, Proceedings of GRAPHICON '96, 6th International Conference and Exhibition on Computer Graphics and Visualization in Russia, (St. Petersburg, Jul. 1-5, 1996) vol. 2, pp. 131-137.

Haeblerli, Paul et al., "Texture Mapping as a Fundamental Drawing Primitive," Proceedings of the Fourth Eurographics Workshop on Rendering, 11 pages, Paris, France (Jun. 1993).

Feth, Bill, "Non-Photorealistic Rendering," wif3@cornerll.edu, CS490—Bruce Land, 5 pages (Spring 1998).

Elber, Gershon, "Line Art Illustrations of Parametric and Implicit Forms," IEEE Transactions on Visualization and Computer Graphics, vol. 4, No. 1, Jan.-Mar. 1998.

Zelevnik, Robert et al. "SKETCH: An Interface for Sketching 3D Scenes," Computer Graphics Proceedings, Annual Conference Series 1996, pp. 163-170.

Computer Graphics World, Dec. 1997.

Reynolds, Craig, "Stylized Depiction in Computer Graphics, Non-Photorealistic, Painterly and Toon Rendering," an annotated survey of online resources, 13 pages, last update May 30, 2000, <http://www.red.com/cwr/painterly.html>.

Render Man Artist Tools, Using Arbitrary Output Variables in Photorealistic Renderman (With Applications), PhotoRealistic Renderman Application Note #24, 8 pages, Jun. 1998, <http://www.pixar.com/products/renderman/toolkit/Toolkit/AppNotes/appnote.24.html>.

Softimage/3D Full Support, "Toon Assistant," 1998 Avid Technology, Inc., 1 page, http://www.softimage.com/3dsupport/techn...uments/3.8/features3.8/re1_notes.56.html.

The RenderMan Interface Version 3.1, (Sep. 1989).

"Renderman Artist Tools, PhotoRealistic RenderMan Tutorial," Pixar (Jan. 1996).

NVIDIA.com, technical presentation, "AGDC Per-Pixel Shading" (Nov. 15, 2000).

NVIDIA.com, technical presentation, Introduction to DX8 Pixel Shaders (Nov. 10, 2000).

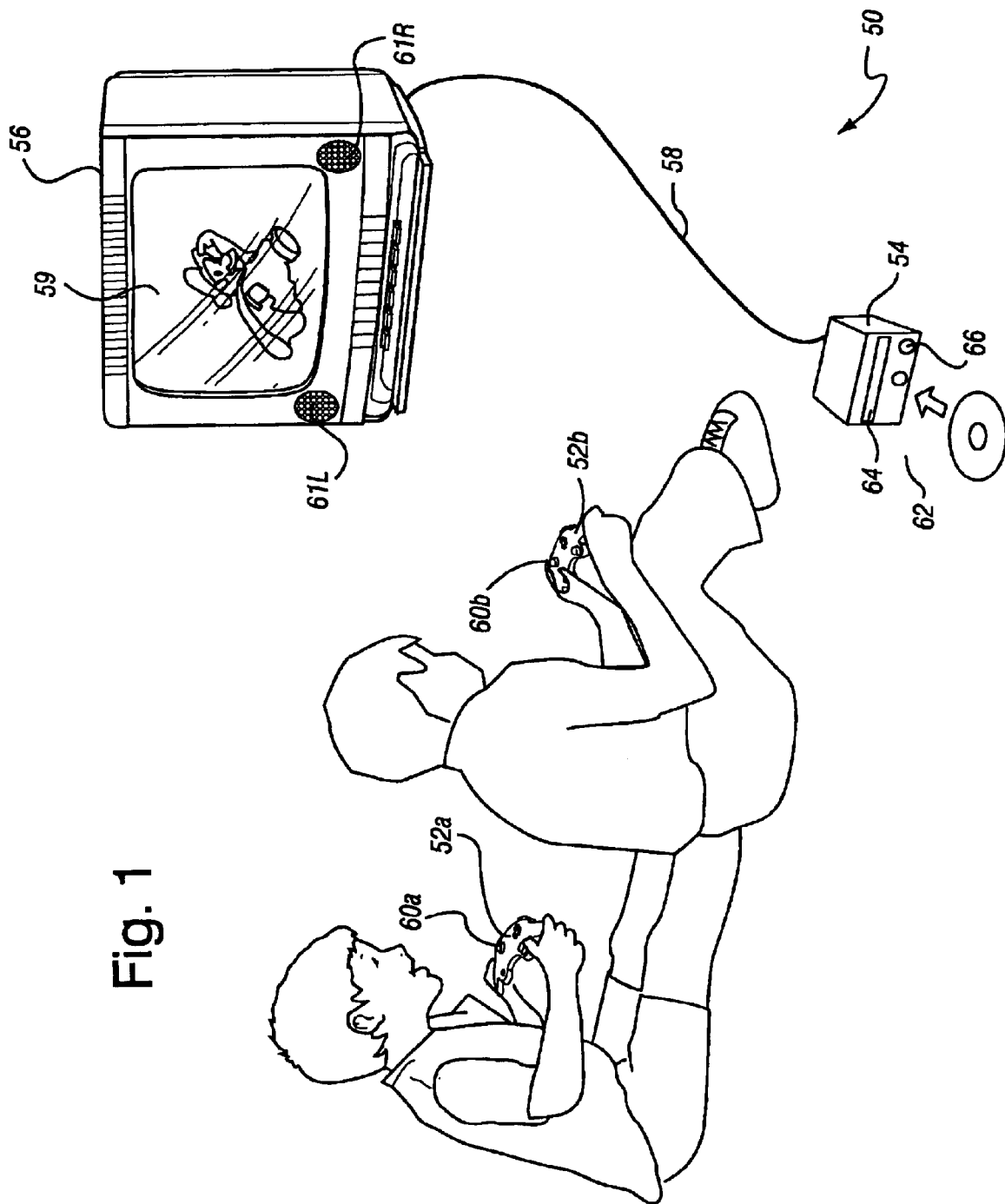
NVIDIA.com, technical presentation, "Advanced Pixel Shader Details" (Nov. 10, 2000).

"Developer's Lair, Multitexturing with the ATI Rage Pro," (7 pages) from ati.com web site (2000).

- "Hardware Technology," from ATI.com web site, 8 pages (2000).
- "Skeletal Animation and Skinning," from ATI.com web site, 2 pages (Summer 2000).
- "Developer Relations, ATI Summer 2000 Developer Newsletter," from ATI.com web site, 5 pages (Summer 2000).
- Press Releases, "ATI's RADEON family products delivers the most comprehensive support for the advance graphics features of DirectX 8.0," Canada, from ATI.com web site, 2 pages (Nov. 9, 2000).
- "ATI RADEON Skinning and Tweening," from ATI.com web site, 1 page (2000).
- Hart, Evan et al., "Vertex Shading with Direct3D and OpenGL," Game Developers Conference 2001, from ATI.com web site (2001).
- Search Results for: skinning, from ATI.com web site, 5 pages (May 24, 2001).
- Hart, Evan et al., "Graphics by rage," Game Developers Conference 2000, from ATI.com web site (2000).
- Efficient Command/Data Interface Protocol For Graphics, IBM TDB, vol. 36, issue 9A, Sep. 1, 1993, pp. 307-312.
- Shade, Jonathan et al., "Layered Depth Images," Computer Graphics Proceedings, Annual Conference Series, pp. 231-242 (1998).
- Videom Conference Pro (PCI) Specification, product of Winnov (Winnov), published Jul. 21, 1999.
- Hoppe, Hugues, "Optimization of Mesh Locality for Transparent Vertex Caching," Proceedings of Siggraph, pp. 269-276 (Aug. 8-13, 1999).
- Whitepaper: Implementing Fog in Direct3D, Jan. 3, 2000, www.nvidia.com.
- Akeley, Kurt, "Reality Engine Graphics", 1993, Silicon Graphics Computer Systems, pp. 109-116.
- Photograph of Sony PlayStation II System.
- Photograph of Sega Dreamcast System.
- Photograph of Nintendo 64 System.
- Whitepaper: 3D Graphics Demystified, Nov. 11, 1999, www.nvidia.com.
- Whitepaper: "Z Buffering, Interpolation and More W-Buffering", Doug Rogers, Jan. 31, 2000, www.nvidia.com.
- Whitepaper: Using GL_NV_vertex_array and GL_NV_fence, posted Aug. 1, 2000, www.nvidia.com.
- Whitepaper: Anisotropic Texture Filtering in OpenGL, posted Jul. 17, 2000, www.nvidia.com.
- Whitepaper: Mapping Texels to Pixels in D3D, posted Apr. 5, 2000, www.nvidia.com.
- Whitepaper: Guard Band Clipping, posted Jan. 31, 2000, www.nvidia.com.
- Whitepaper: Cube Environment Mapping, post Jan. 14, 2000, www.nvidia.com.
- Whitepaper: Color Key in D3D, posted Jan. 11, 2000, www.nvidia.com.
- Whitepaper: Vertex Blending Under DX7 for the GeForce 256, Jan. 5, 2000, www.nvidia.com.
- Whitepaper: Optimizing Direct3D for the GeForce 256, Jan. 3, 2000, www.nvidia.com.
- Whitepaper: Dot Product Texture Blending, Dec. 3, 1999, www.nvidia.com.
- Whitepaper: Technical Brief: AGP 4X with Fast Writes, Nov. 10, 1999, www.nvidia.com.
- Technical Brief: Transform and Lightning, Nov. 10, 1999, www.nvidia.com.
- Technical Brief: What's New With Microsoft DirectX7, posted Nov. 10, 1999, www.nvidia.com.
- Mitchell et al., "Multitexturing in DirectX6", Game Developer, Sep. 1998, www.gdmag.com.
- VisionTek, "GeForce2 GS Graphics Processing Unit", ©2000 www.visiontek.com.
- Jim Bushnell et al. "Advanced Multitexture Effects With Direct3D and OpenGL", Pyramid Peak Design & ATI Research, Inc., GameDevelopers Conference, ©1999.
- Sony PlayStation II Instruction Manual, Sony Computer Entertainment Inc., ©2000.
- Stand and Be Judged, Next Generation, May 2000.
- PlayStation II: Hardware Heaven or Hell?, Next Generation, Jan. 2000.
- Chris Charla, "Play Station II: The Latest News", Next Generation, Sep. 1999.
- "First PlayStation II Gameplay Screens Revealed?", Next Generation, Sep. 1999.
- Game Enthusiast Online Highlights, Mar. 18, 1999.
- Game Enthusiast Online Highlights, Mar. 19, 1999.
- Game Enthusiast Online Highlights, Mar. 17, 1999.
- Game Enthusiast Online Highlights, Oct. 20, 1999.
- Joel Easley, "Playstation II Revealed", Game Week, Sep. 29, 1999.
- Inside Sony's Next Generation Playstation, ©1999.
- Press Releases, Mar. 18, 1999.
- Chris Johnston, "PlayStation Part Deux", Press Start, ©1999.
- Nikkei Shimbun, "Sony Making SME, Chemical and SPT into Wholly-Owned Subsidiaries", Mar. 9, 1999.
- AM News: Japanese Developers Not All Sold on PS2, Next Generation, Mar. 16, 1999.
- Sony To Turn PlayStation Maker Into Wholly Owned Unit—Nikkei, Dow Jones News Service, Mar. 8, 1999.
- Yumiko Ono, Sony Antes Up Its Chips In Bet On New Game System, Dow Jones News Service, Mar. 4, 1999.
- MacWeek.Com Gets Inside Story on Connectix VGS for Windows; Controversial Emulator of Sony PlayStation Games Currenly Available for Macs Only, Business Wire, Mar. 12, 1999.
- "DexDrive Bridges Gap", The Tampa Tribune, Mar. 12, 1999.
- A Microprocessor With a 128b CPU, 10 Floating-Point MAC's, 4 Floating-Point Dividers, and an MPEG2 Decoder, 1999 IEEE International Solid-State Circuits Conference, Feb. 16, 1999.
- Dreamcast Instruction Manual, Sega Enterprises, Ltd., ©1998.
- "Sega To Launch Video Camera for Dreamcast", Reuters Business News, Feb. 16, 2000.
- David Pescovitz, "Dream On", Wired, Aug. 1999.
- Randy Nelson, "Dreamcast 101: Everything You Ever Wanted To Know About Sega's Powerful New Console", Official Sega Dreamcast Magazine, Jun. 1999.
- 2D/3D Graphics Card User Manual, Guillemot ©1999.
- Nintendo 64 Instruction Booklet, Nintendo of America, 1998.
- Steven Levy, "Here Comes PlayStation II", Newsweek, Mar. 6, 2000.
- David Sheff, "Sony Smackage: Test Driving The PlayStation II", Wired, Nov. 1999.
- Introducing The Next Generation PlayStation, Sony Computer Entertainment Inc., ©1999.
- Leadtek GTS, Aug. 3, 2000, www.hexus.net.

- Voodoo 5 5500 Review, Jul. 26, 2000, www.hexus.net.
- ATI Radeon 64 Meg DDR OEM, Aug., 19, 2000, www.hexus.net.
- Microsoft Xbox—The Future of Gaming, Microsoft Xbox Performance Sheet, www.xbox.com.
- Robert L. Cook, “Shade Trees”, *Computer Graphics*, vol. 18, No. 3, Jul. 1984.
- Wang et al., “Second-Depth Shadow Mapping”, Department of Computer Science, Univ. N.C., Chapel Hill, N.C. pp. 1–7.
- Peercy et al., “Efficient Bump Mapping Hardware”, *Computer Graphics Proceedings, Annual Conference Series*, 1997.
- Gustavo Oliveira, “Refractive Texture Mapping, Part One”, www.gamasutra.com, Nov., 10, 2000.
- John Schlag, Fast Embossing Effects on Raster Image Data, *Graphics Gems IV*, Edited by Paul S. Heckbert, Computer Science Department, Carnegie Mellon University, Academic Press, Inc., 1994, pp. 433–437.
- James F. Blinn, “Simulation of Wrinkled Surfaces,” *Caltech/JPL*, pp. 286–292, SIGGRAPH 78 (1978).
- Tomas Möller and Eric Haines “Real-Time Rendering”, AK Peters, Ltd., © 1999, pp. 127–142.
- Technical Presentation: Vertex Buffers, posted Jun. 12, 2000, www.nvidia.com.
- Technical Presentation: Hardware Transform and Lightning, www.nvidia.com, posted Jun. 12, 2000.
- Technical Presentation: Hardware Bump-mapping Choices and Concepts, Jun. 7, 2000, www.nvidia.com.
- Technical Presentation: How to Bump Map a Skinned Polygonal Model, Jun. 7, 2000, www.nvidia.com.
- Technical Presentation: Computations for Hardware Lighting and Shading, Mar. 17, 2000, www.nvidia.com.
- Technical Presentation: Practical Bump-mapping for Today’s GPUs, Mar. 17, 2000 www.nvidia.com.
- Technical Presentation: Shadows, Transparency, & Fog, Mar. 17, 2000 www.nvidia.com.
- Technical Presentation: GeForce 256 Register Combiners, Mar. 17, 2000, www.nvidia.com.
- Technical Presentation: TexGen & The Texture Matrix, Mar. 15, 2000 www.nvidia.com.
- Technical Presentation: Toon Shading, Mar. 15, 2000, www.nvidia.com.
- Technical Presentation: D3D 7 Vertex Lighting, Mar. 15, 2000, www.nvidia.com.
- Technical Presentation: Per-Pixel Lighting (by S. Dietrich) Mar. 14, 2000 www.nvidia.com.
- Technical Presentation: GeForce 256 and RIVA TNT Combiners, Dec. 8, 1999, www.nvidia.com.
- Technical Presentation: Vertex Cache Optimization, Nov. 12, 1999, www.nvidia.com.
- Technical Presentation: Vertex Blending, Nov. 12, 1999, www.nvidia.com.
- Technical Presentation: Hardware Transform and Lighting, Nov. 12, 1999, www.nvidia.com.
- Technical Presentation: GeForce 256 Overview, Nov. 12, 1999, www.nvidia.com.
- Technical Presentation: DirectX 7 and Texture Management, Nov. 12, 1999 www.nvidia.com.
- Technical Presentation: Dot Product Lighting, Nov. 12, 1999, www.nvidia.com.
- Technical Presentation: Texture Coordinate Generation, Nov. 3, 1999, www.nvidia.com.
- Technical Presentation: Phong Shading and Lightmaps, Nov. 3, 1999, www.nvidia.com.
- Technical Presentation: The ARB_multitexture Extension, Nov. 3, 1999 www.nvidia.com.
- Technical Presentation: Multitexture Combiners, Nov. 3, 1999, www.nvidia.com.
- Technical Presentation: Emboss Bump Mapping, Nov. 3, 1999, www.nvidia.com.
- Technical Presentation: Hardware Accelerated Anisotropic Lighting, Nov. 3, 1999, www.nvidia.com.
- Technical Presentation: Guard Band Clipping, Nov. 3, 1999, www.nvidia.com.
- The RenderMan Interface, Stephan R. Keith, Version 3.1, Pixar Animation Studios, Sep. 1989.
- The RenderMan Interface, Version 3.2, Pixar Animation Studios, Jul. 2000, www.pixar.com.
- NVIDIA Product Overview, “GeForce2Ultra”, NVIDIA Corporation, Aug. 21, 2000, www.nvidia.com.
- Duke, “Dreamcast Technical Specs”, Sega Dreamcast Review, Sega, 2/99, www.game-revolution.com.
- Marlin Rowley, “GeForce 1 & 2 GPU Speed Tests”, May 11, 2000, www.g256.com.
- “Dreamcast: The Full Story”, Next Generation, Sep. 1998.
- DirectX 7.0 Programmer’s Reference, Microsoft Corporation, 1995–1999 (as part of the DirectX 7.0 SDK on the Companion CD included with “Inside Direct3D”, Microsoft Programming Series, Peter J. Kovach, Microsoft Press, 1999).
- “Inside Direct3D”, Microsoft Programming Series, Peter J. Kovach, Microsoft Press, 1999.
- “OpenGL Programming Guide, The Official Guide to Learning OpenGL, Release 1”, Jackie Nieder, Tom David, Mason Woo, Addison-Wesley Publishing Co., 1993.
- “Procedural Elements for Computer Graphics,” Second Edition, David F. Rogers, McGraw Hill, 1998.
- “Real-Time Rendering,” Tomas Möller, Eric Haines, AK Peters, 1999.
- “Computer Graphics, Principles and Practice,” Second Edition, The Systems Programming Series, Foley, van Dam, Fiener, Hughes, Addison Wesley, 1990.
- “Principles of Three-Dimensional Computer Animation”, Revised Edition, Michael O’Rourke, W.W. Norton & Company, 1998.

* cited by examiner



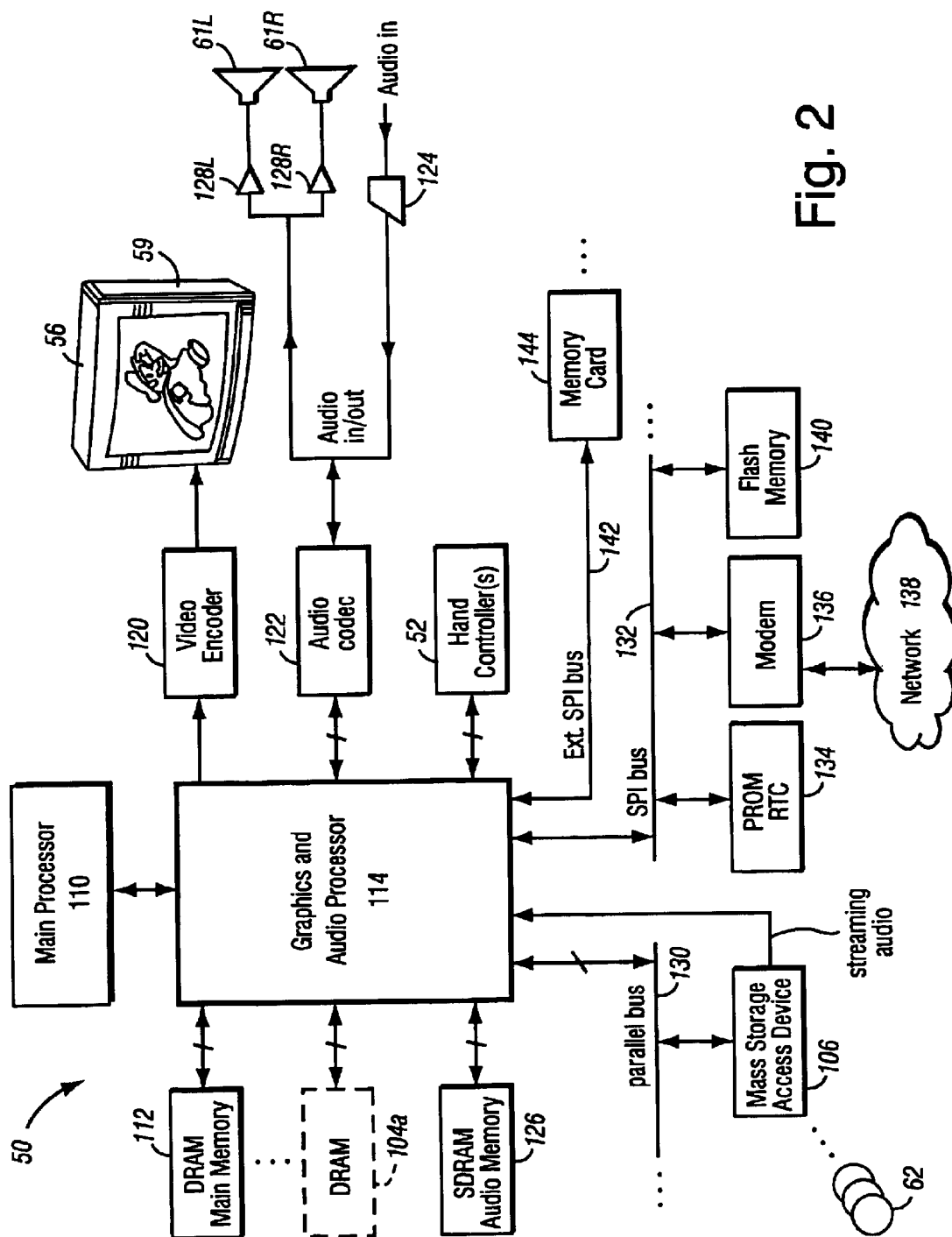
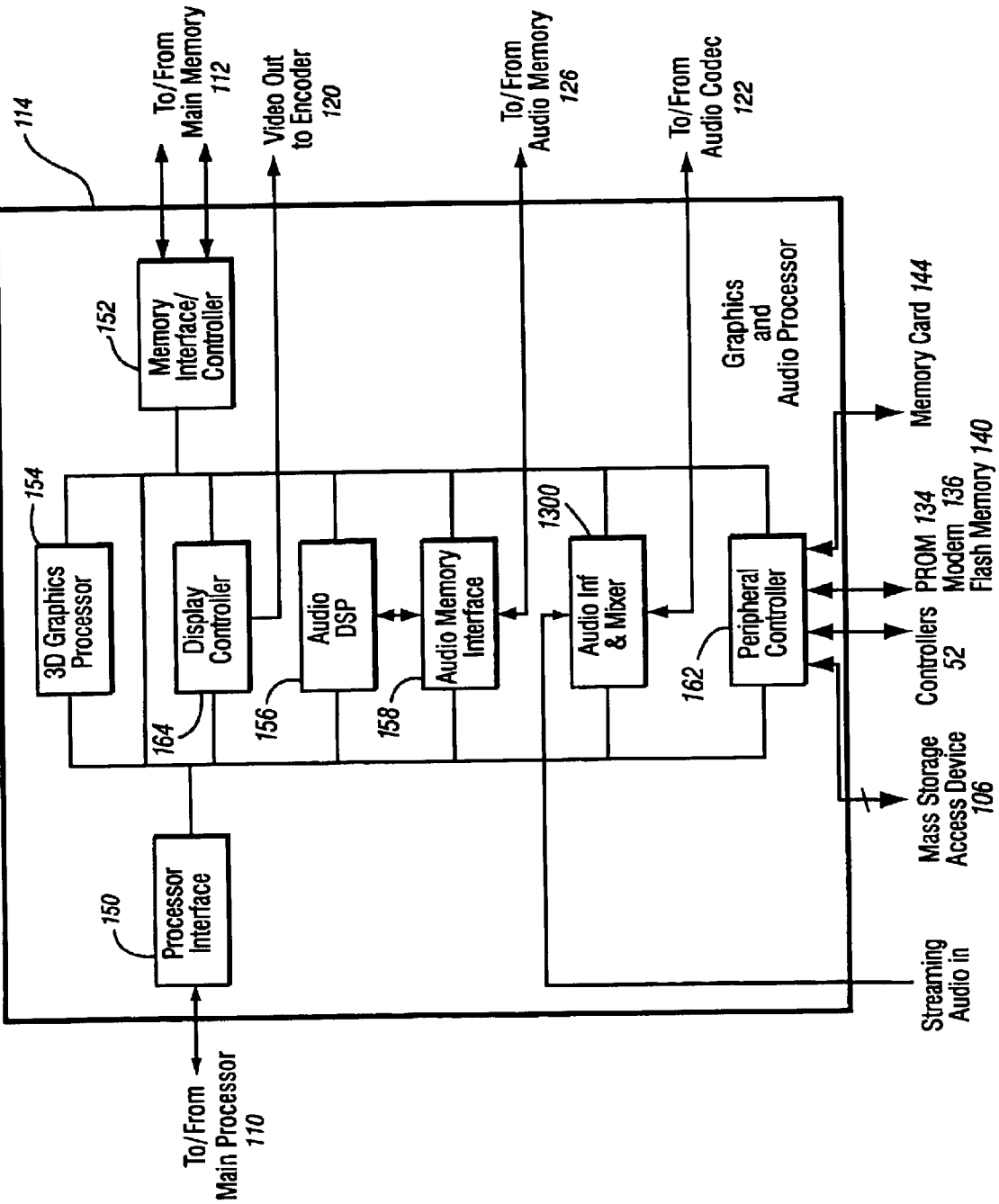


Fig. 2



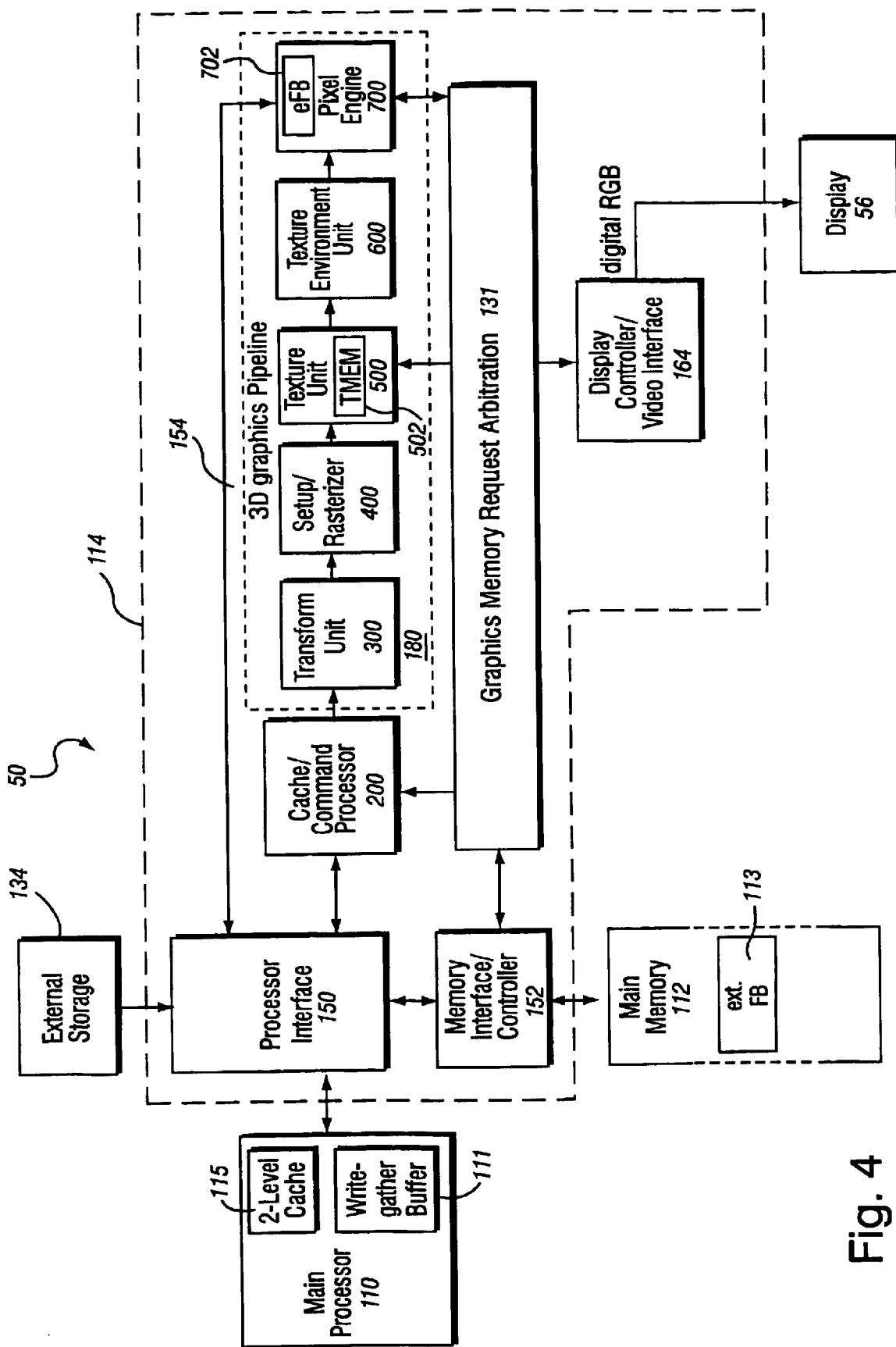


Fig. 4

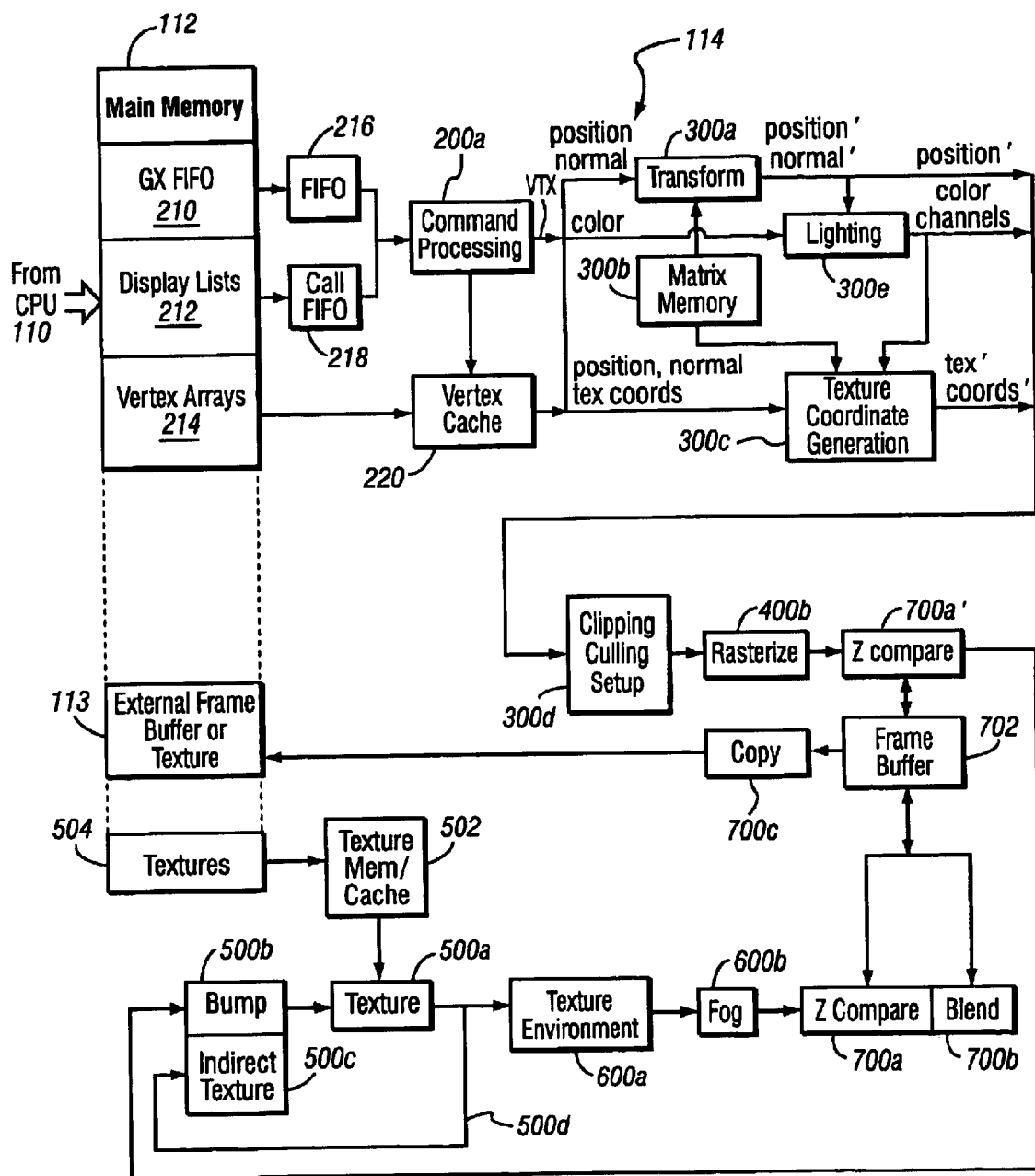
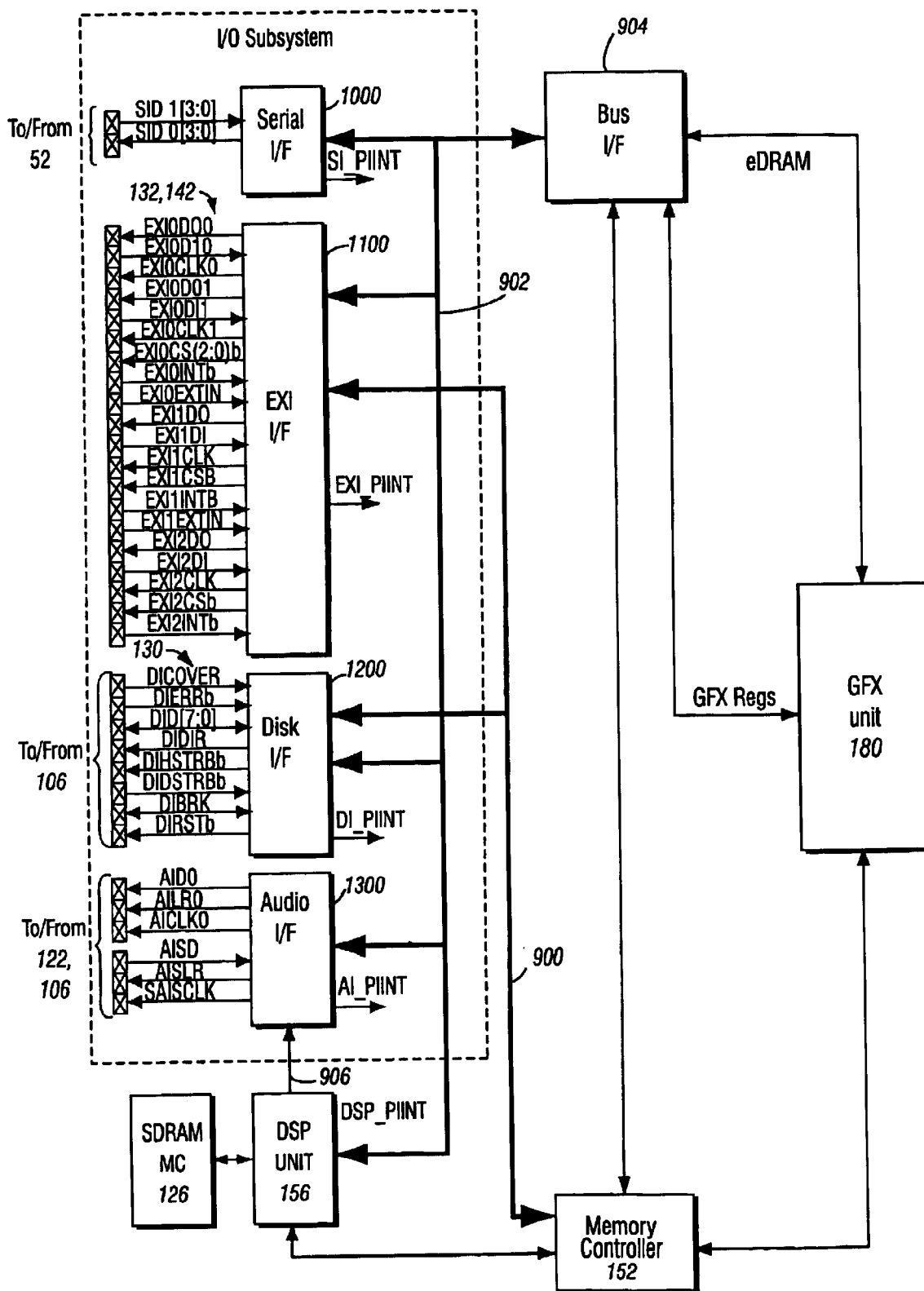


Fig. 5 EXAMPLE GRAPHICS PROCESSOR FLOW

Fig. 6 EXAMPLE INPUT/OUTPUT SUBSYSTEM

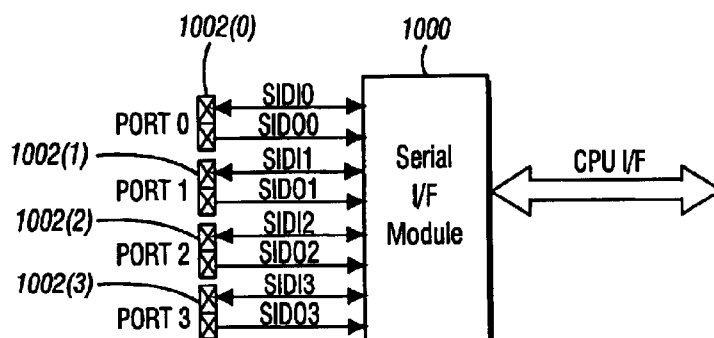


Fig. 7A
EXAMPLE SERIAL INTERFACE

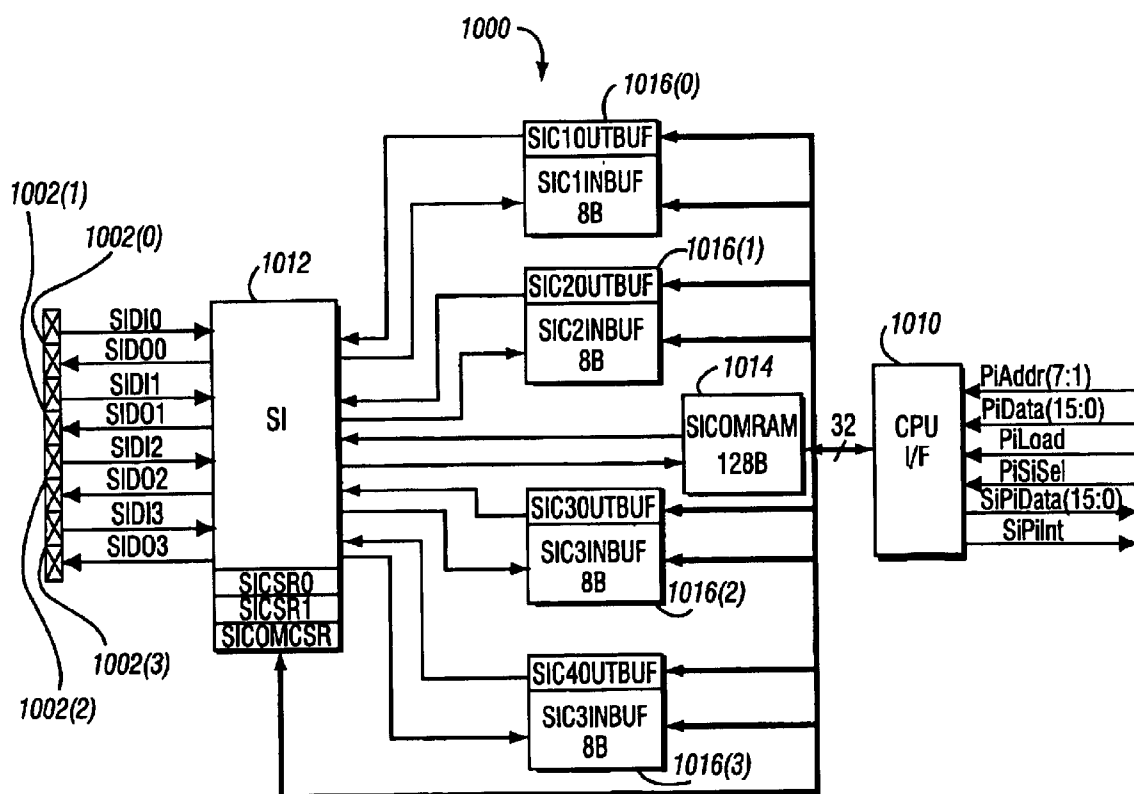
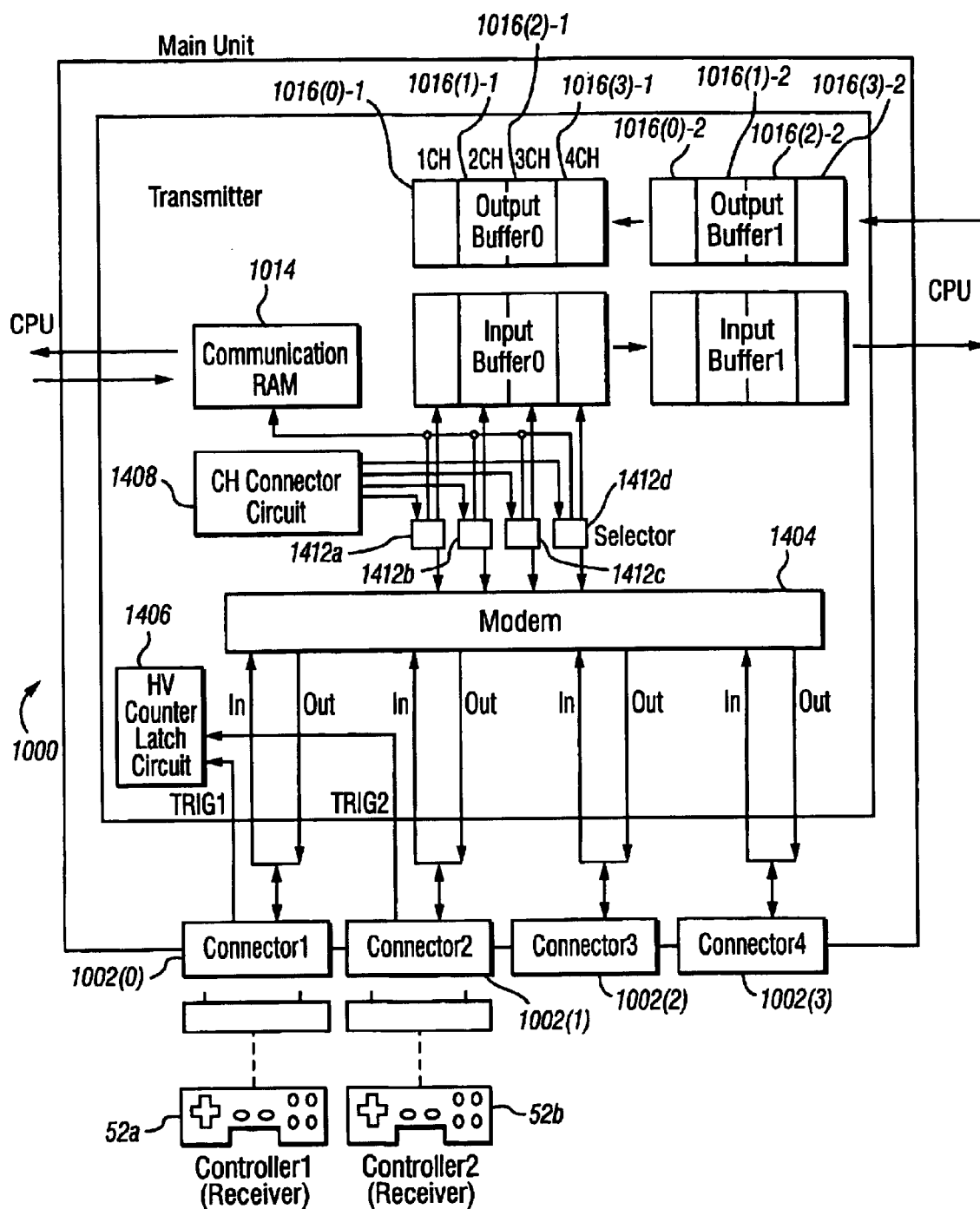


Fig. 7B
EXAMPLE SERIAL INTERFACE

Register				Offset(hex)
31	16	15	0	
SI Channel 0 Output Buffer (SIC0OUTBUF)				0x00
SI Channel 0 Input Buffer H (SIC0INBUFH)				0x04
SI Channel 0 Input Buffer L (SIC0INBUFL)				0x08
SI Channel 1 Output Buffer (SIC1OUTBUF)				0x0C
SI Channel 1 Input Buffer H (SIC1INBUFH)				0x10
SI Channel 1 Input Buffer L (SIC1INBUFL)				0x14
SI Channel 2 Output Buffer (SIC2OUTBUF)				0x18
SI Channel 2 Input Buffer H (SIC2INBUFH)				0x1C
SI Channel 2 Input Buffer L (SIC2INBUFL)				0x20
SI Channel 3 Output Buffer (SIC3OUTBUF)				0x24
SI Channel 3 Input Buffer H (SIC3INBUFH)				0x28
SI Channel 3 Input Buffer L (SIC3INBUFL)				0x2C
SI Poll Control Register (SIPOLL)				0x30
SI Communication Control Status Register (SICOMCSR)				0x34
SI Status Register (SISR)				0x38
SI EXI Lock Register (SIEXILK)				0x3C
SI Communication RAM (128 Bytes)				0x80-0xFF

Fig. 7C

EXAMPLE SERIAL INTERFACE REGISTERS

**Fig. 8**

EXAMPLE SERIAL INTERFACE

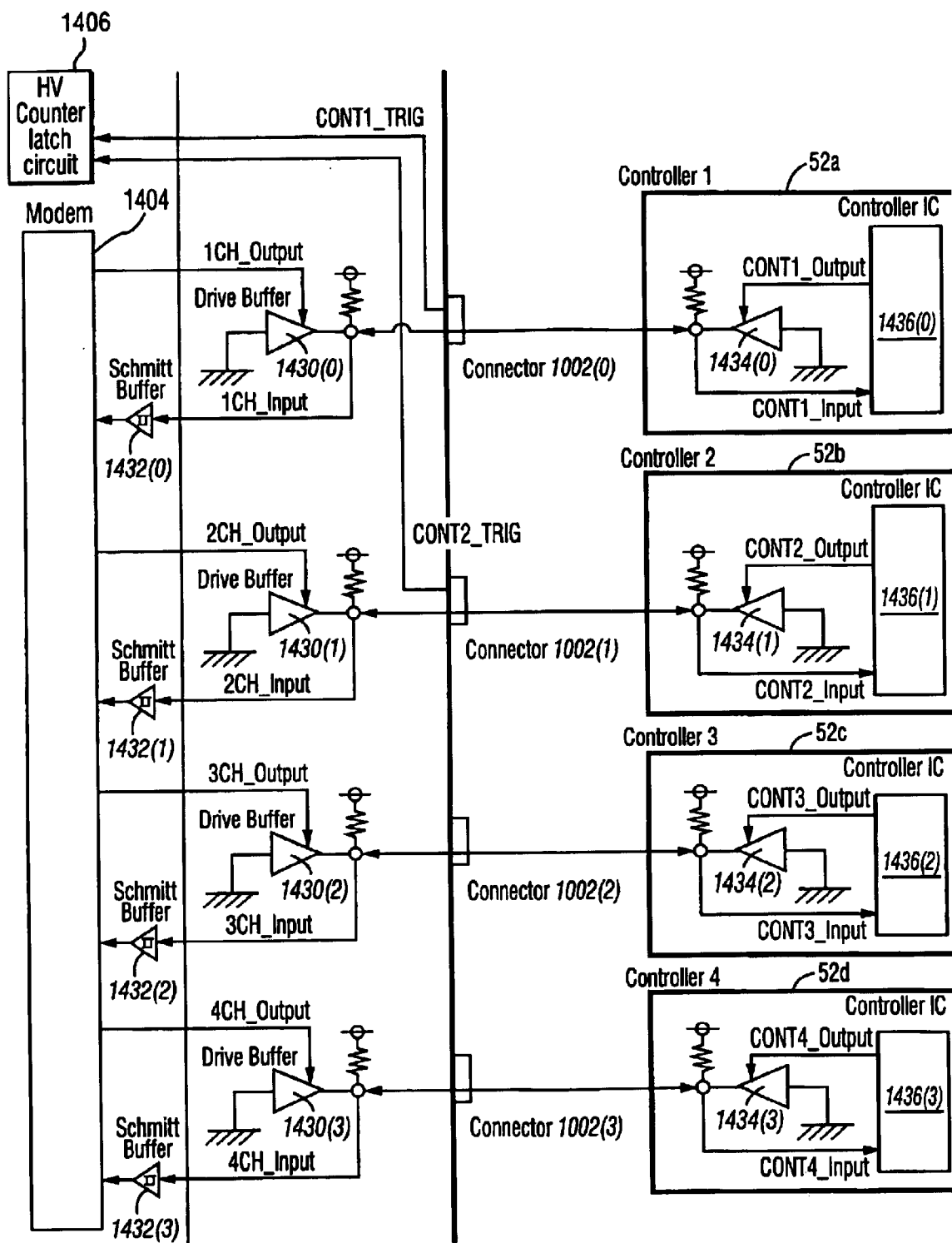


Fig. 9

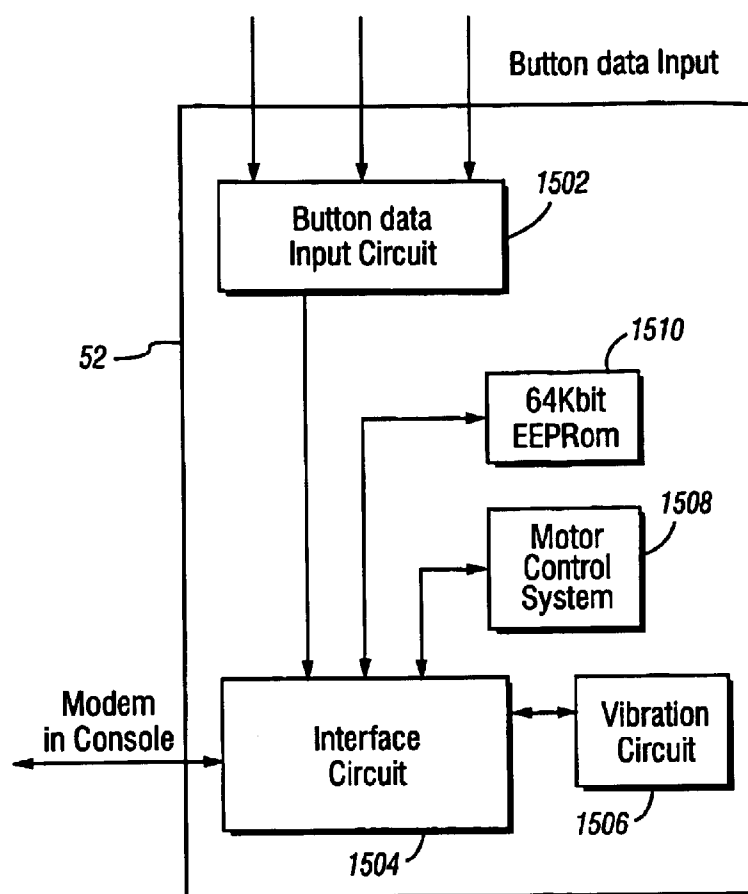


Fig. 10

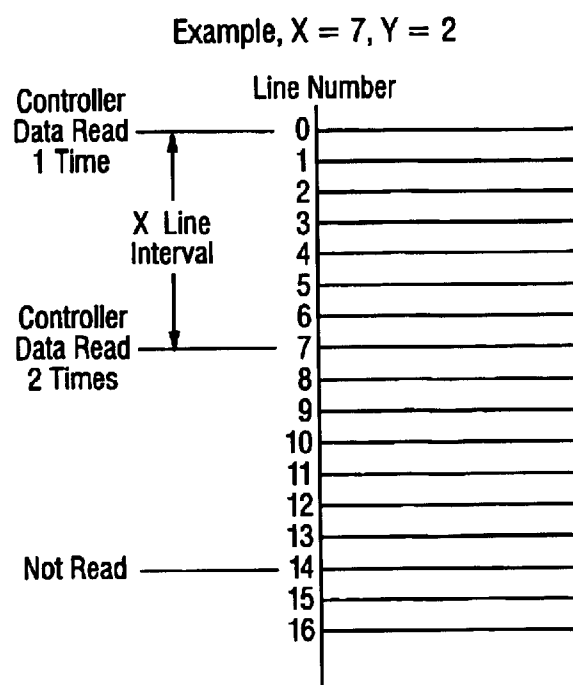


Fig. 12

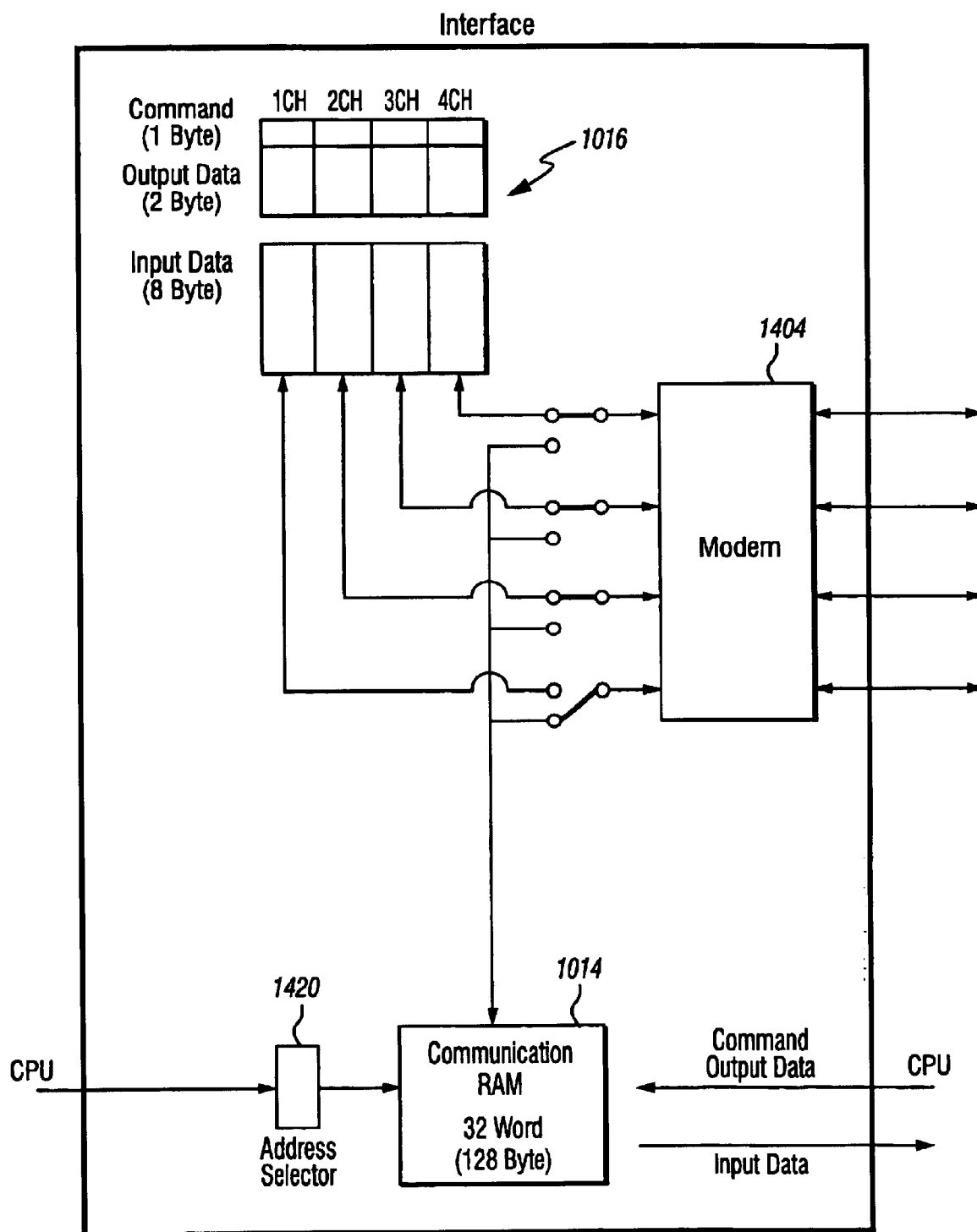


Fig. 11

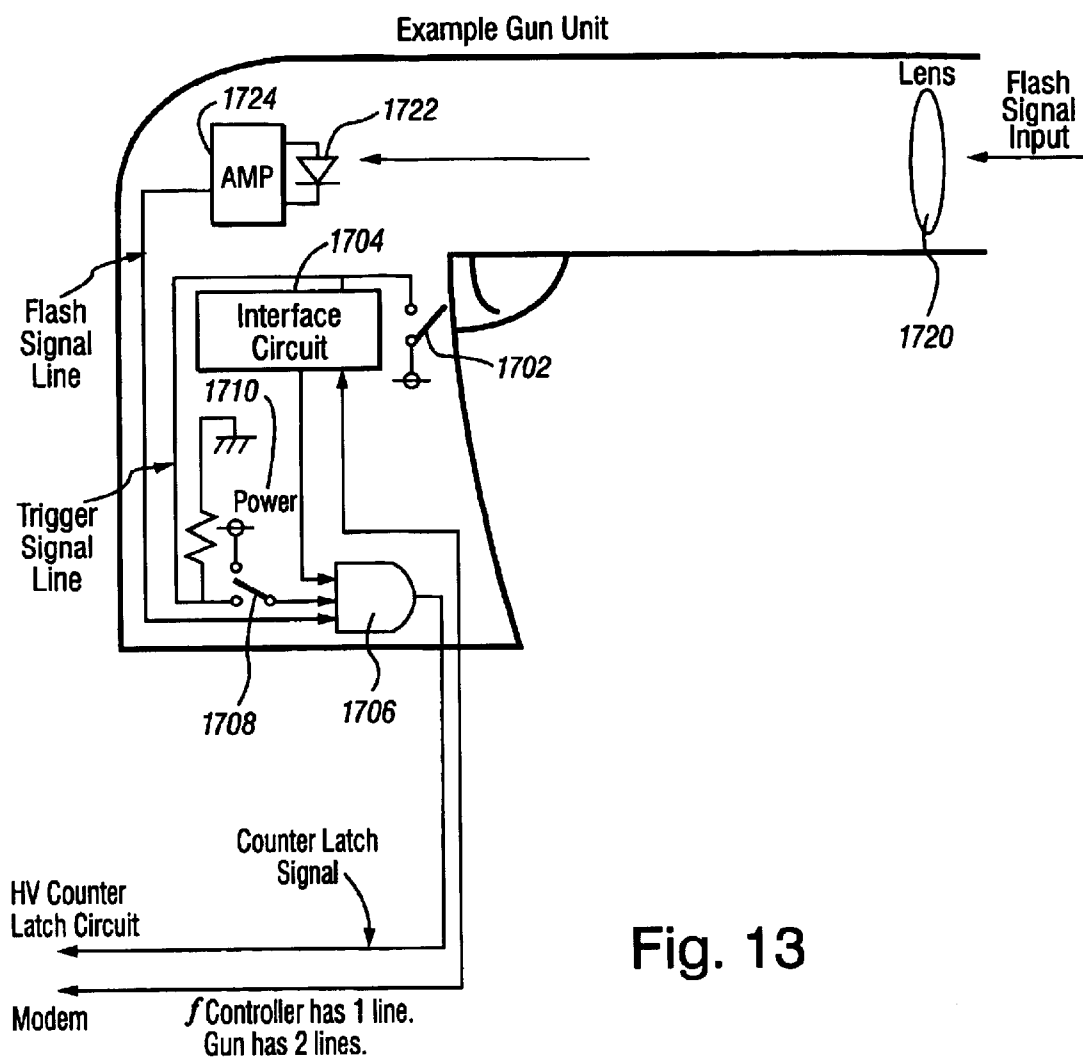
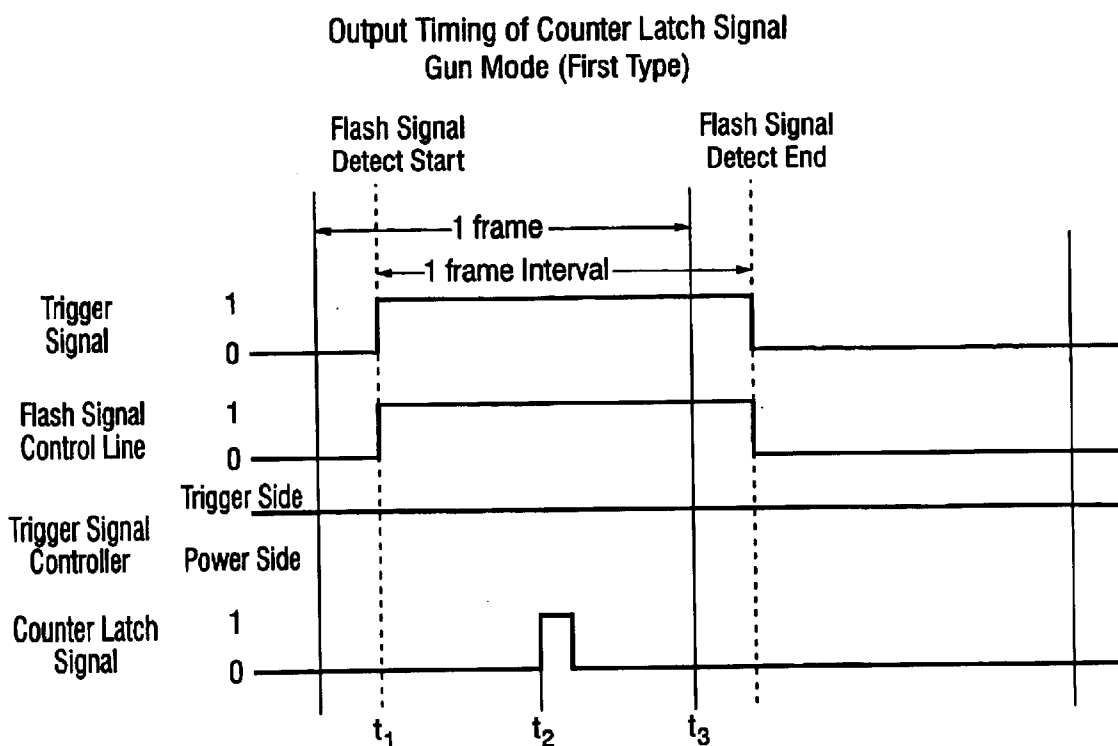
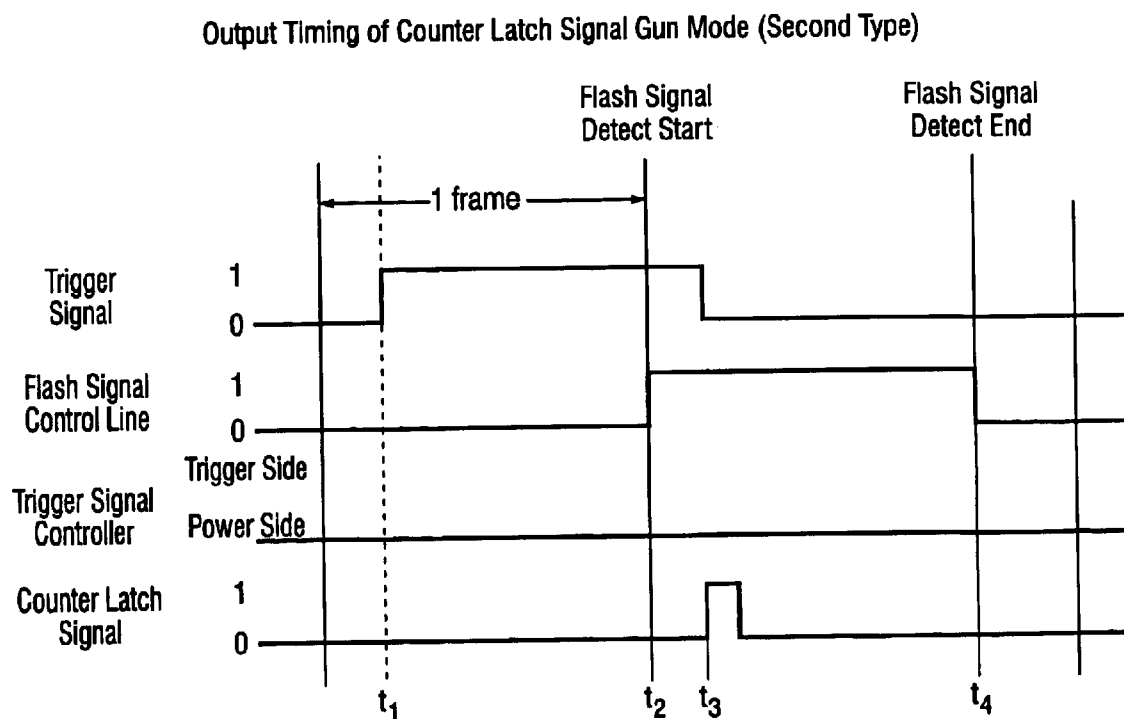


Fig. 13

**Fig. 14A****Fig. 14B**

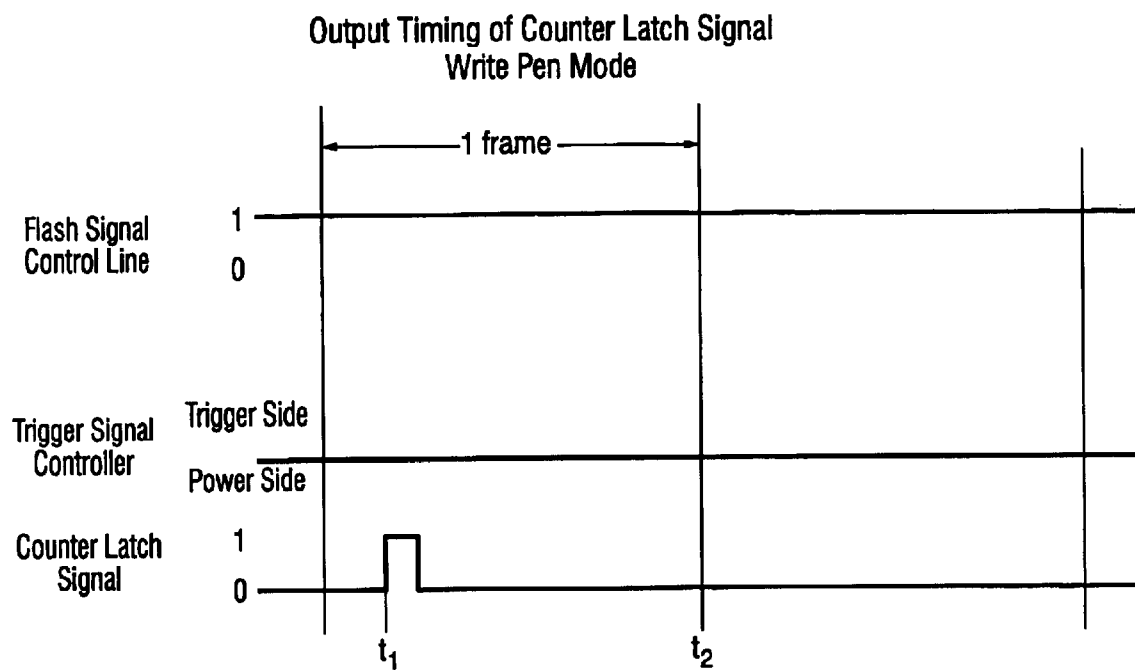
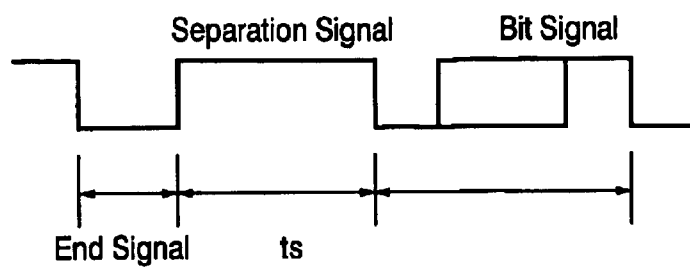
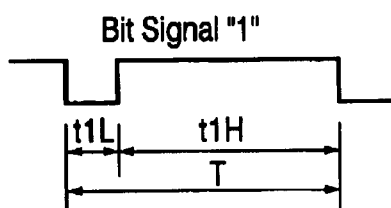


Fig. 14C



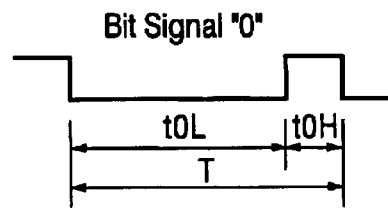
Separation Signal

Fig. 15A



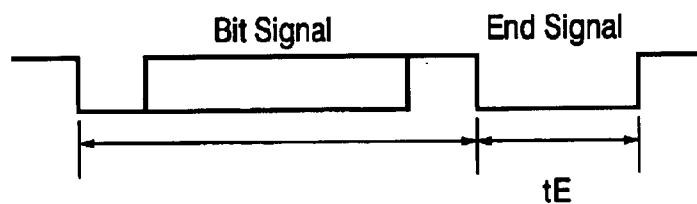
Bit Signal

Fig. 15B



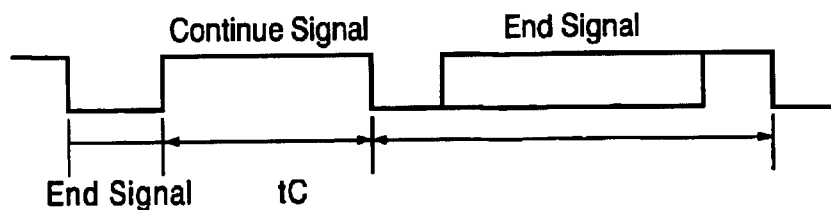
Bit Signal

Fig. 15C



End Signal

Fig. 15D



End Signal

Continue Signal

Fig. 15E



Command Frame
Fig. 16A
Response Frame
Fig. 16B

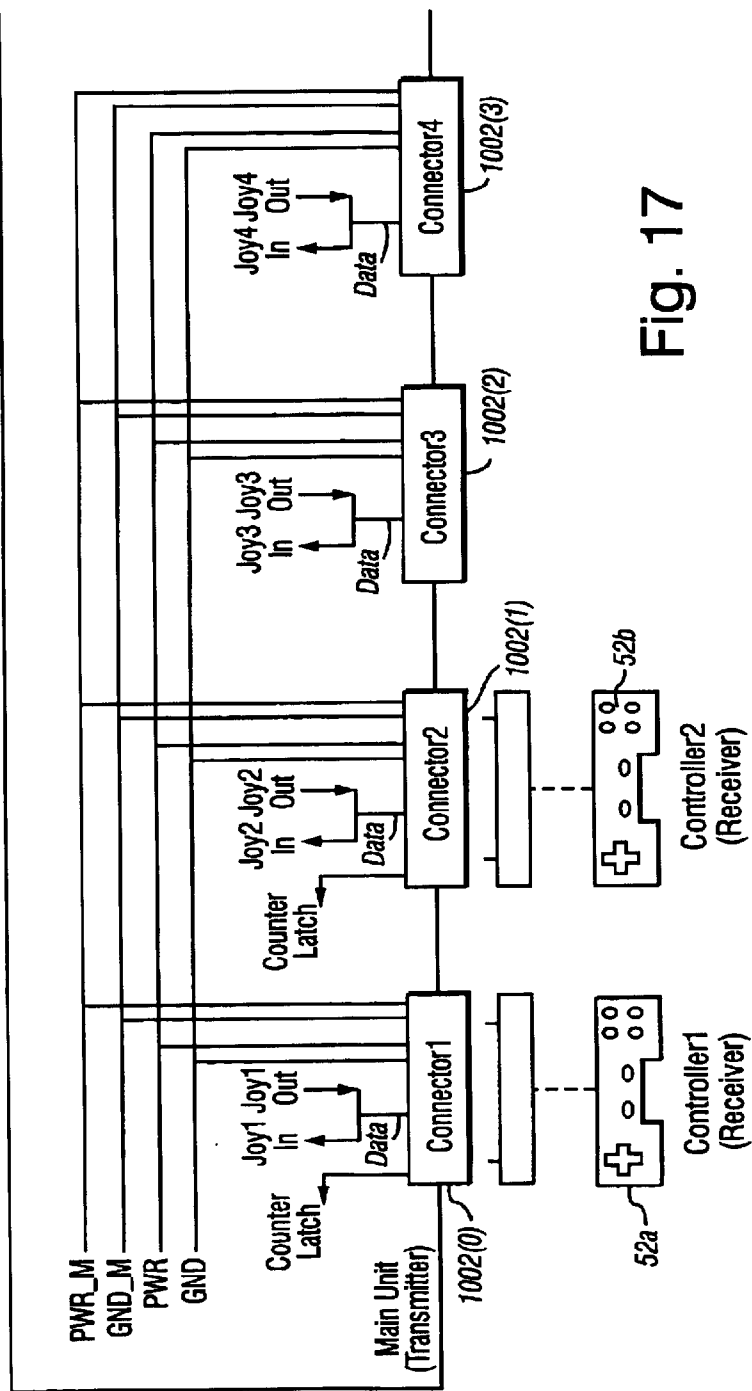


Fig. 17

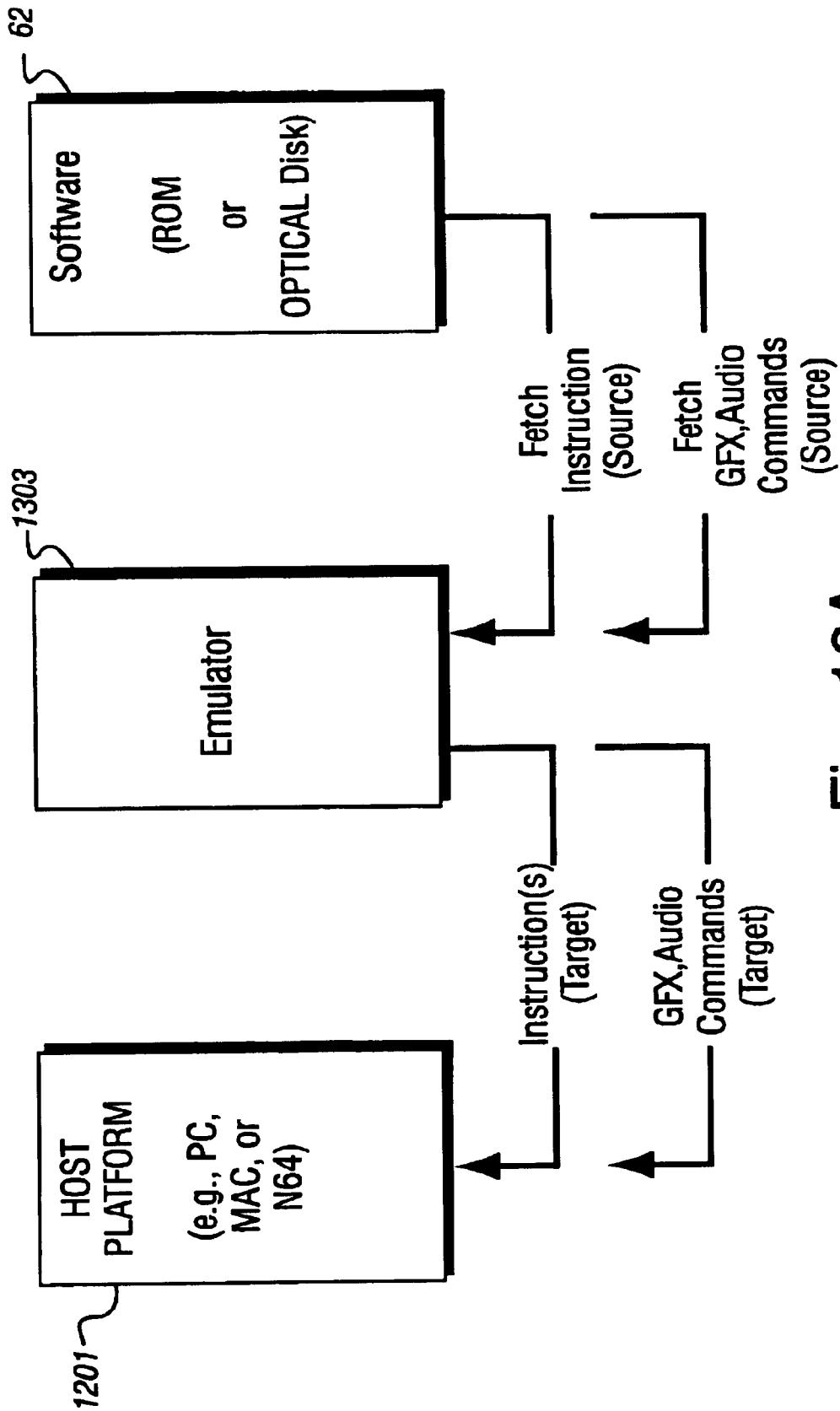


Fig. 18A

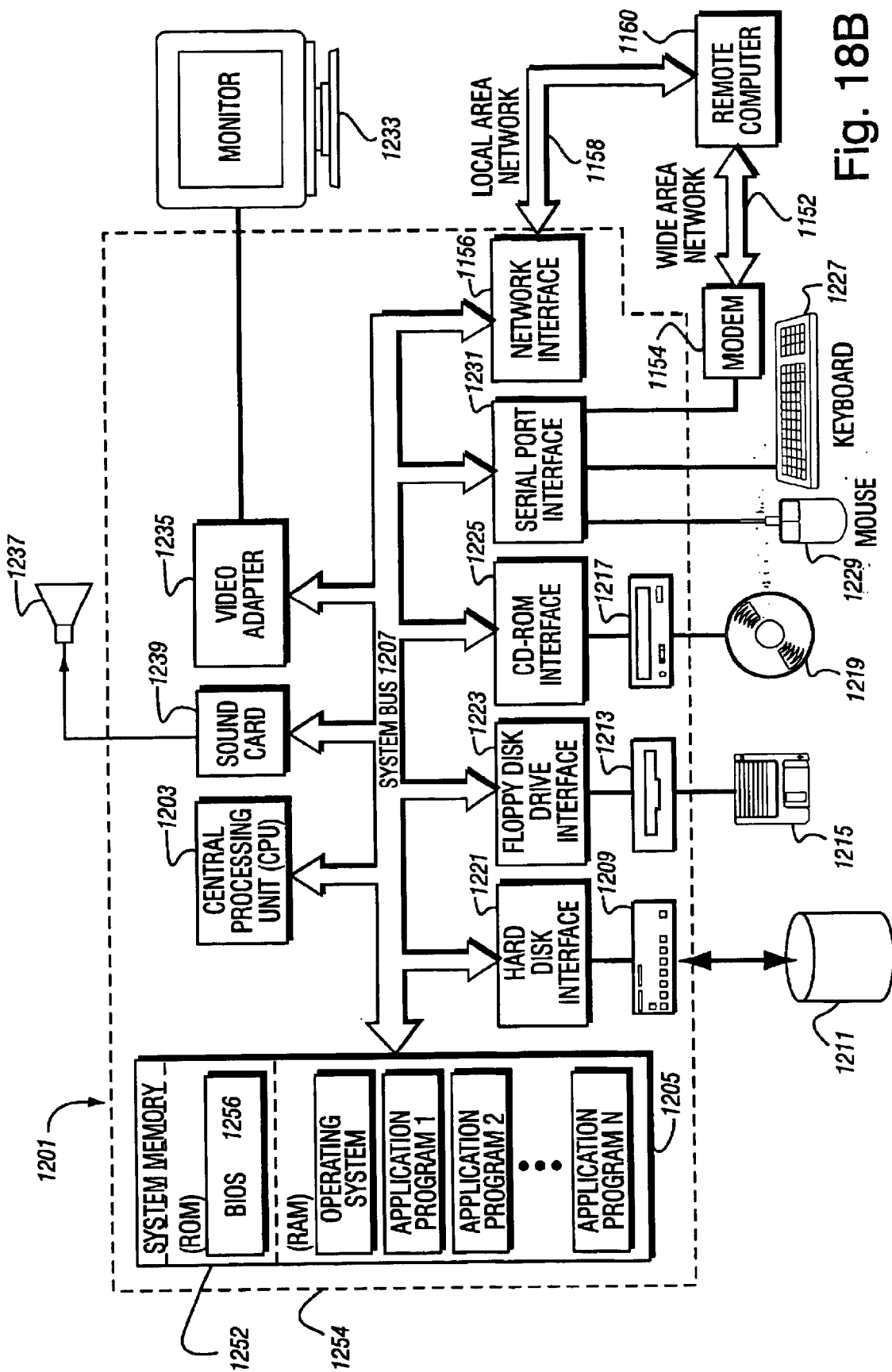


Fig. 18B

1

CONTROLLER INTERFACE FOR A GRAPHICS SYSTEM

RELATED APPLICATIONS

This application claims priority from provisional Application No. 60/226,885, filed Aug. 23, 2000, the contents of which are incorporated herein.

FIELD OF THE INVENTION

The present invention relates to computer graphics, and more particularly to interactive graphics systems such as home video game platforms. Still more particularly this invention relates to a controller interface used to connect a controller to a graphics system.

BACKGROUND AND SUMMARY OF THE INVENTION

Many of us have seen films containing remarkably realistic dinosaurs, aliens, animated toys and other fanciful creatures. Such animations are made possible by computer graphics. Using such techniques, a computer graphics artist can specify how each object should look and how it should change in appearance over time, and a computer then models the objects and displays them on a display such as your television or a computer screen. The computer takes care of a performing the many tasks required to make sure that each part of the displayed image is colored and shaped just right based on the position and orientation of each object in a scene, the direction in which light seems to strike each object, the surface texture of each object, and other factors.

Because computer graphics generation is complex, computer-generated three-dimensional graphics just a few years ago were mostly limited to expensive specialized flight simulators, high-end graphics workstations and supercomputers. The public saw some of the images generated by these computer systems in movies and expensive television advertisements, but most of us couldn't actually interact with the computers doing the graphics generation. All this has changed with the availability of relatively inexpensive 3D graphics platforms such as, for example, the Nintendo 64® and various 3D graphics cards now available for personal computers. It is now possible to interact with exciting 3D animations and simulations on relatively inexpensive computer graphics systems in your home or office.

In an interactive real time system such as a gaming platform, user-manipulable controls are provided for player inputs. The controls may take many forms including buttons, switches, joysticks, trackballs and the like. These player inputs are used during game play, for example, to move characters left, right, up and down; to take character actions such as jumping; etc. Thus, in game systems, some means must be provided to interface with user-manipulable controls such as hand-held controllers or the like. The present invention provides such an interface. More specifically, the present invention provides an interface for interfacing an audio and graphics coprocessor with a variety of different types of accessory devices including but not limited to hand-held game controllers. The serial interface provides a single bit serial interface using a state-based interface protocol. The interface supports four separate serial interfaces to four hand-held controllers or associated devices. Each interface can be accessed in parallel. In a controller mode, the last state of the controller is stored in a double-buffered register to support simple main processor reads for determining state. The example embodiment automatically polls

2

controller state using hardware circuitry with configurable polling periods. A bulk mode supports changeable data size. A pair of light gun signals can be used to control separate horizontal/vertical counters to support flash and shutter light guns. An LCD shutter can be supported through automatic polling and a serial control command. The system interface includes automatic control of presence detect to save effort on the part of the main processor.

In accordance with one particular aspect of the present invention, a video game system includes a game program executing system executing a game program and one or more controllers supplying user inputs to the game program executing system. An interface between the controllers and the game program executing system is programmable to periodically poll the controller without involvement of the game program executing system.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages provided by the invention will be better and more completely understood by referring to the following detailed description of presently preferred embodiments in conjunction with the drawings, of which:

FIG. 1 is an overall view of an example interactive computer graphics system;

FIG. 2 is a block diagram of the FIG. 1 example computer graphics system;

FIG. 3 is a block diagram of the example graphics and audio processor shown in FIG. 2;

FIG. 4 is a block diagram of the example 3D graphics processor shown in FIG. 3;

FIG. 5 is an example logical flow diagram of the FIG. 4 graphics and audio processor;

FIG. 6 shows an example input/output subsystem;

FIGS. 7A and 7B show an example serial interface;

FIG. 7C shows example serial interface registers;

FIG. 8 shows a more detailed view of the serial interface of FIGS. 7A and 7B;

FIG. 9 shows a more detailed view of a portion of the serial interface shown in FIG. 8;

FIG. 10 shows an example controller;

FIG. 11 shows the example system elements involved in data transfers using a communication RAM;

FIG. 12 is used to illustrate the meaning of the X line interval register and the Y times register;

FIG. 13 shows an example light gun;

FIGS. 14A–14C are timing diagrams for explaining the light gun and light pen operations;

FIGS. 15A–15E depict signals used in data transfer;

FIG. 16 illustrates the communication protocol between the serial interface and the controllers;

FIG. 17 depicts the lines for the channels of serial interface 1000; and

FIGS. 18A and 18B show example alternative compatible implementations.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS OF THE INVENTION

FIG. 1 shows an example interactive 3D computer graphics system 50. System 50 can be used to play interactive 3D video games with interesting stereo sound. It can also be used for a variety of other applications.

3

In this example, system **50** is capable of processing, interactively in real time, a digital representation or model of a three-dimensional world. System **50** can display some or all of the world from any arbitrary viewpoint. For example, system **50** can interactively change the viewpoint in response to real time inputs from handheld controllers **52a**, **52b** or other input devices. This allows the game player to see the world through the eyes of someone within or outside of the world. System **50** can be used for applications that do not require real time 3D interactive display (e.g., 2D display generation and/or non-interactive display), but the capability of displaying quality 3D images very quickly can be used to create very realistic and exciting game play or other graphical interactions.

To play a video game or other application using system **50**, the user first connects a main unit **54** to his or her color television set **56** or other display device by connecting a cable **58** between the two. Main unit **54** produces both video signals and audio signals for controlling color television set **56**. The video signals are what controls the images displayed on the television screen **59**, and the audio signals are played back as sound through television stereo loudspeakers **61L**, **61R**.

The user also needs to connect main unit **54** to a power source. This power source may be a conventional AC adapter (not shown) that plugs into a standard home electrical wall socket and converts the house current into a lower DC voltage signal suitable for powering the main unit **54**. Batteries could be used in other implementations.

The user may use hand controllers **52a**, **52b** to control main unit **54**. Controls **60** can be used, for example, to specify the direction (up or down, left or right, closer or further away) that a character displayed on television **56** should move within a 3D world. Controls **60** also provide input for other applications (e.g., menu selection, pointer/cursor control, etc.). Controllers **52** can take a variety of forms. In this example, controllers **52** shown each include controls **60** such as joysticks, push buttons and/or directional switches. Controllers **52** may be connected to main unit **54** by cables or wirelessly via electromagnetic (e.g., radio or infrared) waves.

To play an application such as a game, the user selects an appropriate storage medium **62** storing the video game or other application he or she wants to play, and inserts that storage medium into a slot **64** in main unit **54**. Storage medium **62** may, for example, be a specially encoded and/or encrypted optical and/or magnetic disk. The user may operate a power switch **66** to turn on main unit **54** and cause the main unit to begin running the video game or other application based on the software stored in the storage medium **62**. The user may operate controllers **52** to provide inputs to main unit **54**. For example, operating a control **60** may cause the game or other application to start. Moving other controls **60** can cause animated characters to move in different directions or change the user's point of view in a 3D world. Depending upon the particular software stored within the storage medium **62**, the various controls **60** on the controller **52** can perform different functions at different times.

Example Electronics of Overall System

FIG. 2 shows a block diagram of example components of system **50**. The primary components include:

- a main processor (CPU) **110**,
- a main memory **112**, and
- a graphics and audio processor **114**.

In this example, main processor **110** (e.g., an enhanced IBM Power PC 750) receives inputs from handheld control-

4

lers **52** (and/or other input devices) via graphics and audio processor **114**. Main processor **110** interactively responds to user inputs, and executes a video game or other program supplied, for example, by external storage media **62** via a mass storage access device **106** such as an optical disk drive. As one example, in the context of video game play, main processor **110** can perform collision detection and animation processing in addition to a variety of interactive and control functions.

In this example, main processor **110** generates 3D graphics and audio commands and sends them to graphics and audio processor **114**. The graphics and audio processor **114** processes these commands to generate interesting visual images on display **59** and interesting stereo sound on stereo loudspeakers **61R**, **61L** or other suitable sound-generating devices.

Example system **50** includes a video encoder **120** that receives image signals from graphics and audio processor **114** and converts the image signals into analog and/or digital video signals suitable for display on a standard display device such as a computer monitor or home color television set **56**. System **50** also includes an audio codec (compressor/decompressor) **122** that compresses and decompresses digitized audio signals and may also convert between digital and analog audio signaling formats as needed. Audio codec **122** can receive audio inputs via a buffer **124** and provide them to graphics and audio processor **114** for processing (e.g., mixing with other audio signals the processor generates and/or receives via a streaming audio output of mass storage access device **106**). Graphics and audio processor **114** in this example can store audio related information in an audio memory **126** that is available for audio tasks. Graphics and audio processor **114** provides the resulting audio output signals to audio codec **122** for decompression and conversion to analog signals (e.g., via buffer amplifiers **128L**, **128R**) so they can be reproduced by loudspeakers **61L**, **61R**.

Graphics and audio processor **114** has the ability to communicate with various additional devices that may be present within system **50**. For example, a parallel digital bus **130** may be used to communicate with mass storage access device **106** and/or other components. A serial peripheral bus **132** may communicate with a variety of peripheral or other devices including, for example:

- a programmable read-only memory (PROM) and/or real time clock (RTC) **134**,
- a modem **136** or other networking interface (which may in turn connect system **50** to a telecommunications network **138** such as the Internet or other digital network from/to which program instructions and/or data can be downloaded or uploaded), and
- a flash memory **140**.

A further external serial bus **142** may be used to communicate with additional expansion memory **144** (e.g., a memory card) or other devices. Connectors may be used to connect various devices to busses **130**, **132**, **142**.

Example Graphics and Audio Processor

FIG. 3 is a block diagram of an example graphics and audio processor **114**. Graphics and audio processor **114** in one example may be a single-chip ASIC (application specific integrated circuit). In this example, graphics and audio processor **114** includes:

- a processor interface **150**,
- a memory interface/controller **152**,
- a 3D graphics processor **154**,
- an audio digital signal processor (DSP) **156**,
- an audio memory interface **158**,

5

an audio interface and mixer **1300**,
a peripheral controller **162**, and
a display controller **164**.

3D graphics processor **154** performs graphics processing tasks. Audio digital signal processor **156** performs audio processing tasks. Display controller **164** accesses image information from main memory **112** and provides it to video encoder **120** for display on display device **56**. Audio interface and mixer **1300** interfaces with audio codec **122**, and can also mix audio from different sources (e.g., streaming audio from mass access storage device **106**, the output of audio DSP **156**, and external audio input received via audio codec **122**). Processor interface **150** provides a data and control interface between main processor **110** and graphics and audio processor **114**.

Memory interface **152** provides a data and control interface between graphics and audio processor **114** and memory **112**. In this example, main processor **110** accesses main memory **112** via processor interface **150** and memory interface **152** that are part of graphics and audio processor **114**. Peripheral controller **162** provides a data and control interface between graphics and audio processor **114** and the various peripherals mentioned above. Audio memory interface **158** provides an interface with audio memory **126**.

Example Graphics Pipeline

FIG. 4 shows a more detailed view of an example 3D graphics processor **154**. 3D graphics processor **154** includes, among other things, a command processor **200** and a 3D graphics pipeline **180**. Main processor **110** communicates streams of data (e.g., graphics command streams and display lists) to command processor **200**. Main processor **110** has a two-level cache **115** to minimize memory latency, and also has a write-gathering buffer **111** for uncached data streams targeted for the graphics and audio processor **114**. The write-gathering buffer **111** collects partial cache lines into full cache lines and sends the data out to the graphics and audio processor **114** one cache line at a time for maximum bus usage.

Command processor **200** receives display commands from main processor **110** and parses them—obtaining any additional data necessary to process them from shared memory **112**. The command processor **200** provides a stream of vertex commands to graphics pipeline **180** for 2D and/or 3D processing and rendering. Graphics pipeline **180** generates images based on these commands. The resulting image information may be transferred to main memory **112** for access by display controller/video interface unit **164**—which displays the frame buffer output of pipeline **180** on display **56**.

FIG. 5 is a logical flow diagram of graphics processor **154**. Main processor **110** may store graphics command streams **210**, display lists **212** and vertex arrays **214** in main memory **112**, and pass pointers to command processor **200** via bus interface **150**. The main processor **110** stores graphics commands in one or more graphics first-in-first-out (FIFO) buffers **210** it allocates in main memory **112**. The command processor **200** fetches:

command streams from main memory **112** via an on-chip FIFO memory buffer **216** that receives and buffers the graphics commands for synchronization/flow control and load balancing,

display lists **212** from main memory **112** via an on-chip call FIFO memory buffer **218**, and

vertex attributes from the command stream and/or from vertex arrays **214** in main memory **112** via a vertex cache **220**.

6

Command processor **200** performs command processing operations **200a** that convert attribute types to floating point format, and pass the resulting complete vertex polygon data to graphics pipeline **180** for rendering/rasterization. A programmable memory arbitration circuitry **131** (see FIG. 4) arbitrates access to shared main memory **112** between graphics pipeline **180**, command processor **200** and display controller/video interface unit **164**.

FIG. 4 shows that graphics pipeline **180** may include:

- a transform unit **300**,
- a setup/rasterizer **400**,
- a texture unit **500**,
- a texture environment unit **600**, and
- a pixel engine **700**.

Transform unit **300** performs a variety of 2D and 3D transform and other operations **300a** (see FIG. 5). Transform unit **300** may include one or more matrix memories **300b** for storing matrices used in transformation processing **300a**. Transform unit **300** transforms incoming geometry per vertex from object space to screen space; and transforms incoming texture coordinates and computes projective texture coordinates (**300c**). Transform unit **300** may also perform polygon clipping/culling **300d**. Lighting processing **300e** also performed by transform unit **300** provides per vertex lighting computations for up to eight independent lights in one example embodiment. Transform unit **300** can also perform texture coordinate generation (**300c**) for embossed type bump mapping effects, as well as polygon clipping/culling operations (**300d**).

Setup/rasterizer **400** includes a setup unit which receives vertex data from transform unit **300** and sends triangle setup information to one or more rasterizer units (**400b**) performing edge rasterization, texture coordinate rasterization and color rasterization.

Texture unit **500** (which may include an on-chip texture memory (TMEM) **502**) performs various tasks related to texturing including for example:

- retrieving textures **504** from main memory **112**,
- texture processing (**500a**) including, for example, multi-texture handling, post-cache texture decompression, texture filtering, embossing, shadows and lighting through the use of projective textures, and BLIT with alpha transparency and depth,
- bump map processing for computing texture coordinate displacements for bump mapping, pseudo texture and texture tiling effects (**500b**), and indirect texture processing (**500c**).

Texture unit **500** outputs filtered texture values to the texture environment unit **600** for texture environment processing (**600a**). Texture environment unit **600** blends polygon and texture color/alpha/depth, and can also perform texture fog processing (**600b**) to achieve inverse range based fog effects. Texture environment unit **600** can provide multiple stages to perform a variety of other interesting environment-related functions based for example on color/alpha modulation, embossing, detail texturing, texture swapping, clamping, and depth blending.

Pixel engine **700** performs depth (z) compare (**700a**) and pixel blending (**700b**). In this example, pixel engine **700** stores data into an embedded (on-chip) frame buffer memory **702**. Graphics pipeline **180** may include one or more embedded DRAM memories **702** to store frame buffer and/or texture information locally. Z compares **700a'** can also be performed at an earlier stage in the graphics pipeline **180** depending on the rendering mode currently in effect (e.g., z compares can be performed earlier if alpha blending is not

required). The pixel engine **700** includes a copy operation **700c** that periodically writes on-chip frame buffer **702** to memory portion **113** of main memory **112** for access by display/video interface unit **164**. This copy operation **700c** can also be used to copy embedded frame buffer **702** contents to textures in the main memory **112** for dynamic texture synthesis effects. Anti-aliasing and other filtering can be performed during the copy-out operation. The frame buffer output of graphics pipeline **180** (which is ultimately stored in main memory **112**) is read each frame by display/video interface unit **164**. Display controller/video interface **164** provides digital RGB pixel values for display on display **56**.

Example Input/Output Subsystem

FIG. **6** shows an example input/output subsystem. In this example, the input/output subsystem includes a serial interface **1000**, an external interface **1100**, a disk interface **1200** and an audio interface **1300**. Serial interface **1000** is used to communicate with controllers **52** or other devices that can be coupled to one of four serial ports of system **50**. External interface **1100** is used to communicate with a variety of devices such as PROM RTC **134**, modem **136**, flash memory **140**, memory card **144**, etc. via various buses **132**, **142**. Disk interface **1200** is used to communicate with mass storage access device **106** via a parallel bus **130**. Audio interface **1300** is used to stream the audio output data from an audio buffer in main memory **112** to audio codec **122**.

In the example embodiment, the external interface **1100** and disk interface **1200** have direct access to memory controller **152** via a bus **900**. Details of the operation of memory controller **152** may be found in provisional Application No. 60/226,894, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/726,220, filed Nov. 28, 2000, both entitled "Graphics Processing System with Enhanced Memory Controller" and provisional Application No. 60/226,886, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,665, filed Nov. 28, 2000, both entitled "Method and Apparatus for Accessing Shared Resources." The contents of each of these applications are incorporated herein by reference. In addition, each one of interfaces **1000**, **1100**, **1200** and **1300** as well as audio digital signal processor **156** share a common bus **902** used to communicate between these components and a bus interface **904**. The bus interface **904**, in turn, can be used to arbitrate access to graphics unit **180**. In the example embodiment, there is also a connection **906** between DSP **156** and audio interface **1300**.

Briefly, disk interface **1200** provides an interface to mass storage access device **106** providing a direct memory access (DMA) capability with interrupt. Serial interface **1000** provides a serial interface to hand controllers **52** or other serial devices using automatic controller polling and bulk data mode. The serial interface also includes a light gun interface.

The external interface **1100** provides multiple SBI buses as well as a memory-mapped area for boot PROM **134**. Audio interface **1300** provides an output to audio codec **122** as well as an input for streaming audio from mass storage access device **106**.

Example Serial Interface

FIGS. **7A** and **7B** show an example serial interface **1000**. In this particular example, serial interface **1000** is a single bit serial interface that runs at 250 kHz. This single bit serial interface is similar to the controller interface used in the prior art Nintendo 64® product manufactured by Nintendo, but there are some differences. Example serial interface **1000** provides the following features in the example embodiment:

four separate 250 kHz serial interfaces for four controllers **52**,

each interface can be accessed in parallel,

in controller mode, the last state of the controller **52** is in a double-buffered processor input/output register so that main processor **110** can simply read the register to determine the controller state,

the controller state is automatically polled by hardware with configurable polling periods,

bulk mode (changeable data size),

two light gun signals are used to control two separate horizontal/vertical counters to support both flash and shutter light guns,

an LCD shutter is supported through automatic polling and serial control commands, and

the serial interface **1000** can automatically detect the presence of hand controllers **52**.

FIG. **7A** shows the external interface of serial interface **1000**. In this example, there are four separate controller ports **1002** on system **50**. Each port **1002** has a pair of input and output pins (shown by the "x" mark blocks in FIG. **7A**). The input pin connects directly to an external game controller **52** in the example embodiment. The output pin in the example embodiment connects to an external open-drain driver (see FIG. **9**) which in turn connects directly to the external game controller **52**. In the example embodiment, two of the ports **1002** have horizontal/vertical latch signals that can be used to latch horizontal/vertical counters within the video interface **164**. These signals combined with the functionality of serial interface **1000** provide support for flash and shutter type light guns. The vertical latch and control registers used for this functionality are located in the video interface **164** in the example embodiment. FIG. **7A** shows each of the four serial ports **1002** including an SIDI (bi-directional) line and an SIDO (uni-directional) controller output-to-serial interface line. The following shows example descriptions of these two signals:

Name	Dir	Type	Description
SIDI[3:0]	I	LVC MOS	Serial Interface Data Input: SIDI[3:0] are input signals, each bit is a separate half-duplex, 250kbit/s input serial channel. The serial protocol is an asynchronous interface and is self timed, using a pulse width modulated signaling scheme.
SIDO[3:0]	O	LVC MOS	Serial Interface Data Output: SIDO[3:0] are output signals, each bit is a separate half-duplex, 250kbit/s output serial channel. The serial protocol is an asynchronous interface and, is self timed, using a pulse width modulated signaling scheme.

FIG. 7B is a more detailed block diagram of serial interface **1000**. As shown in this Figure, serial interface **1000** includes a main processor interface **1010**, serial interface communication circuitry and registers **1012**, a small (128 byte) communication RAM **1014**, and an input/output buffer arrangement **1016** for each of the four serial ports **1002**.

FIG. 7C shows an example set of registers (register map) used to control serial interface **1000** in the example embodiment. The base address for these serial interface registers in the example embodiment is 0x0C006400. The following describes each of these various example registers in the example embodiment:

SIC0OUTBUF SI Channel 0 Output Buffer				
Mnemonic: SIC0OUTBUF				
Offset: 0x00				
Size 32 bits				
SIC0OUTBUF				
Bits	Mnemonic	Type	Reset	Description
31 . . . 24	CMD	R	0x0	Reserved
23 . . . 16		RW	0x0	Command: This byte is the opcode for the command sent to the controller during each command/response packet. This is the first data byte sent from the SI I/F to the game controller in the command/response packet.
15 . . . 8	OUTPUT0	RW	0x0	Output Byte 0: This is the first data byte of the command packet. It is the second data byte sent from the SI I/F to the game controller in the command/response packet.
7 . . . 0	OUTPUT1	RW	0x0	Output Byte 1: This is the second data byte of the command packet. It is the third data byte sent from the SI I/F to the game controller in the command/response packet.

This register is double buffered, so main processor writes to the SIC0OUTBUF will not interfere with the serial interface output transfer. Internally, a second buffer is used to hold the output data to be transferred across the serial interface. To check if SIC0OUTBUF has been transferred to the second buffer, main processor **110** polls the SISR [WRST0] register. When SIC0OUTBUF is transferred, SISR[WRST0] is cleared.

SIC0INBUF SI Channel 0 Input Buffer High				
Mnemonic: SIC0INBUFH				
Offset: 0x04				
Size 32 bits				
SIC0INBUFH				
Bits	Mnemonic	Type	Reset	Description
31	ERRSTAT	R	0x0	Error Status: This bit represents the current error status for the last SI polling transfer on channel 0. This register is updated after each polling transfer on this channel. 0 = No error on last transfer 1 = Error on last transfer
30	ERRLATCH	R	0x0	Error Latch: This bit is an error status summary of the SISR error bits for this channel. If an error has occurred on a past SI transfer on channel 0 (polling or Com transfer), this bit will be set. To determine the exact error, read the SISR register. This bit is actually an 'or' of the latched error status bits for channel 0 in the SISR. The bit is cleared by clearing the appropriate error status bits latched in the SISR. The no response error indicates that a controller is not present on this channel. 0 = No errors latched 1 = Error latched. Check SISR.
29 . . . 24	INPUT0	R	0x0	Input Byte 0: This is the first data byte of the response packet sent from the game controller to the SI I/F for channel 0. The top two bits of the byte returning from the controller are assumed to be '0', so they are not included.
23 . . . 16	INPUT1	R	0x0	Input Byte 1: This is the second data byte of the response packet sent from the game controller to the SI I/F for channel 0.

-continued

SIC0INBUF SI Channel 0 Input Buffer High				
Mnemonic: SIC0INBUFH				
Offset: 0x04				
Size 32 bits				
SIC0INBUFH				
Bits	Mnemonic	Type	Reset	Description
15 . . . 8	INPUT2	R	0x0	Input Byte 2: This is the third data byte of the response packet sent from the game controllers to the SI I/F for channel 0.
7:0	INPUT3	R	0x0	Input Byte 3: This is the fourth data byte of the response packet sent from the game controller to the SI I/F for channel 0.

15

SIC0INBUFH and SIC0INBUFL are double buffered to prevent inconsistent data reads due to the main processor 110 conflicting with incoming serial interface data. To insure data read from SIC0INBUFH and SIC0INBUFL are 20 consistent, a locking mechanism prevents the double buffer

from copying new data to these registers. Once SIC0INBUFH is read, both SIC0INBUFH and SIC0INBUFL are 'locked' until SIC0INBUFL is read. While the buffers are 'locked', new data is not copied into the buffers. When SIC0INBUFL is read, the buffers become unlocked again.

SIC0INBUF SI Channel 0 Input Buffer Low				
Mnemonic: SIC0INBUFL				
Offset: 0x08				
Size 32 bits				
SIC0INBUFL				
Bits	Mnemonic	Type	Reset	Description
31 . . . 24	INPUT4	R	0x0	Input Byte 4: See Description of SIC1INBUFH[INPUT1].
23 . . . 16	INPUT5	R	0x0	Input Byte 5: See Description of SIC1INBUFH[INPUT1].
15 . . . 8	INPUT6	R	0x0	Input Byte 6: See Description of SIC1INBUFH[INPUT1].
7 . . . 0	INPUT7	R	0x0	Input Byte 7: See Description of SIC1INBUFH[INPUT1].

SIC1OUTBUF SI Channel 1 Output Buffer				
Mnemonic: SIC1OUTBUF				
Offset: 0x0C				
Size 32 bits				
SIC1OUTBUF				
Bits	Mnemonic	Type	Reset	Description
31 . . . 24	CMD	R	0x0	Reserved
23 . . . 16		RW	0x0	Command: For SI channel 1. See SIC0OUTBUF[CMD] description.
15 . . . 8	OUTPUT0	RW	0x0	OutputByte 0: For SI channel 1. See SIC0OUTBUF[OUTPUT0] description.
7 . . . 0	OUTPUT1	RW	0x0	Output Byte 1: For SI channel 1. See SIC0OUTBUF[OUTPUT1] description.

SIC1INBUF SI Channel 1 Input Buffer High				
Mnemonic: SIC1INBUFH				
Offset: 0x10				
Size 32 bits				
SIC1INBUFH				
Bits	Mnemonic	Type	Reset	Description
31	ERRSTAT	R	0x0	Error Status: See Description of SIC0INBUFH[ERRSTAT].
30	ERRLATCH	R	0x0	Error Latch: See Description of SIC0INBUFH[ERRLATCH].
29 . . . 24	INPUT0	R	0x0	Input Byte 0: See Description of SIC0INBUFH[INPUT0].
23 . . . 16	INPUT1	R	0x0	Input Byte 1: See Description of SIC0INBUFH[INPUT1].
15 . . . 8	INPUT2	R	0x0	Input Byte 2: See Description of SIC0INBUFH[INPUT1].

-continued

7 . . . 0	INPUT3	R	0x0	Input Byte 3: See Description of SIC0INBUFH[INPUT1].
SIC1INBUF SI Channel 1 Input Buffer Low Mnemonic: SIC1INBUFL Offset: 0x14 Size 32 bits SIC1INBUFL				
Bits	Mnemonic	Type	Reset	Description
31 . . . 24	INPUT4	R	0x0	Input Byte 4: See Description of SIC0INBUFH[INPUT1].
23 . . . 16	INPUT5	R	0x0	Input Byte 5: See Description of SIC0INBUFH[INPUT1].
15 . . . 8	INPUT6	R	0x0	Input Byte 6: See Description of SIC0INBUFH[INPUT1].
7 . . . 0	INPUT7	R	0x0	Input Byte 7: See Description of SIC0INBUFH[INPUT1].
SIC2OUTBUF SI Channel 2 Output Buffer Mnemonic: SIC2OBUF Offset: 0x18 Size 32 bits SIC2OUTBUF				
Bits	Mnemonic	Type	Reset	Description
31 . . . 24	CMD	R	0x0	Reserved
23 . . . 16		RW	0x0	Command: For SI Channel 2. See SIC0OUTBUFF[CMD] description
15 . . . 8	OUTPUT0	RW	0x0	Output Byte 0: For SI channel 2. See SIC0OUTBUFF[OUTPUT0] description.
7 . . . 0	OUTPUT1	RW	0x0	Output Byte 1: For SI channel 2. See SIC0OUTBUFF[OUTPUT1] description.
SIC2INBUF SI Channel 2 Input Buffer High Mnemonic: SIC2INBUFH Offset: 0x1C Size 32 bits SIC2INBUFH				
Bits	Mnemonic	Type	Reset	Description
31	ERRSTAT	R	0x0	Error Status: See Description of SIC0INBUFH[ERRSTAT].
30	ERRLATCH	R	0x0	Error Latch: See Description of SIC0INBUFH[ERRLATCH].
29 . . . 24	INPUT0	R	0x0	Input Byte 0: See Description of SIC0INBUFH[INPUT1].
23 . . . 16	INPUT1	R	0x0	Input Byte 1: See Description of SIC0INBUFH[INPUT0].
15 . . . 8	INPUT2	R	0x0	Input Byte 2: See Description of SIC0INBUFH[INPUT1].
7 . . . 0	INPUT3	R	0x0	Input Byte 3: See Description of SIC0INBUFH[INPUT1].
SIC2INBUF SI Channel 2 Input Buffer Low Mnemonic: SIC2INBUFL Offset: 0x20 Size 32 bits SIC2INBUFL				
Bits	Mnemonic	Type	Reset	Description
31 . . . 24	INPUT4	R	0x0	Input Byte 4: See Description of SIC0INBUFH[INPUT0].
23 . . . 16	INPUT5	R	0x0	Input Byte 5: See Description of SIC0INBUFH[INPUT0].
15 . . . 8	INPUT6	R	0x0	Input Byte 6: See Description of SIC0INBUFH[INPUT0].
7 . . . 0	INPUT7	R	0x0	Input Byte 7: See Description of SIC0INBUFH[INPUT0].
SIC3OUTBUF SI Channel 3 Output Buffer Mnemonic: SIC3OBUF Offset: 0x24				

-continued

		Size 32 bits SIC3OUTBUF		
Bits	Mnemonic	Type	Reset	Description
31 . . . 24	CMD	R	0x0	Reserved
23 . . . 16		RW	0x0	Command: For SI channel 3. See SIC0OUTBUF[CMD] description
15 . . . 8		RW	0x0	Output Byte 0: For SI channel 3. See SIC0OUTBUF[OUTPUT0] description
7 . . . 0		RW	0x0	Output Byte 1: For SI channel 3. See SIC0OUTBUF[OUTPUT1] description
SIC3INBUF SI Channel 3 Input Buffer High Mnemonic: SIC3INBUFH Offset: 0x28 Size 32 bits SIC3INBUFH				
Bits	Mnemonic	Type	Reset	Description
31	ERRSTAT	R	0x0	Error Status: See Description of SIC0INBUFH[ERRSTAT].
30	ERRLATCH	R	0x0	Error Latch: See Description of SIC0INBUFH[ERRLATCH].
29 . . . 24	INPUT0	R	0x0	Input Byte 0: See Description of SIC0INBUFH[INPUT0].
23 . . . 16	INPUT1	R	0x0	Input Byte 1: See Description of SIC0INBUFH[INPUT1].
15 . . . 8	INPUT2	R	0x0	Input Byte 2: See Description of SIC0INBUFH[INPUT1].
7 . . . 0	INPUT3	R	0x0	Input Byte 3: See Description of SIC0INBUFH[INPUT1].
SIC3INBUF SI Channel 3 Input Buffer Low Mnemonic: SIC3INBUFL Offset: 0x2C Size 32 bits SIC4INBUFL				
Bits	Mnemonic	Type	Reset	Description
31 . . . 24	INPUT4	R	0x0	Input Byte 4: See Description of SIC0INBUFH[INPUT1].
23 . . . 16	INPUT5	R	0x0	Input Byte 5: See Description of SIC0INBUFH[INPUT1].
15 . . . 8	INPUT6	R	0x0	Input Byte 6: See Description of SIC0INBUFH[INPUT1].
7 . . . 0	INPUT7	R	0x0	Input Byte 7: See Description of SIC0INBUFH[INPUT1].
SIPOLL SI Poll Register Mnemonic: SIPOLL Offset: 0x30 Size 32 bits SIPOLL				
Bits	Mnemonic	Type	Reset	Description
31 . . . 26	X	R	0x0	Reserved
25 . . . 16		RW	0x07	X lines register: determines the number of horizontal video lines between polling (the polling interval). The polling begins at vsync. 0x07 is the minimum setting (determined by the time required to complete a single polling of the controller). The maximum setting depends on the current video mode (number of lines per vsync) and the SIPOLL[Y] register. This register takes affect after vsync.
15 . . . 8	Y	RW	0x0	Y times register: This register determines the number of times the SI controllers are polled in a single frame. This register takes affect after vsync.
7	EN0	RW	0x0	Enable channel 0: Enable polling of channel 0. When the channel is enabled, polling begins at the next vblank. When the channel is disabled, polling is stopped immediately after the current transaction. The status of this bit does not affect communication RAM transfers on this channel. 1 = Polling of channel 0 is enabled 0 = Polling of channel 0 is disabled

-continued

6	EN1	RW	0x0	Enable channel 1: See description for SIPOLL[EN0].
5	EN2	RW	0x0	Enable channel 2: See Description for SIPOLL[EN0].
4	EN3	RW	0x0	Enable channel 3: See Description for SIPOLL[EN0].
3	VBCPY0	RW	0x0	Vblank copy output channel 0: Normally main processor writes to the SIC0OUTBUF register are copied immediately to the channel 0 output buffer if a transfer is not currently in progress. When this bit is asserted, main processor writes to channel 0's SIC0OUTBUF will only be copied to the outbuffer on vblank. This is used to control the timing of commands to 3D LCD shutter glasses connected to the VI. 1 = Copy SIC0OUTBUF to output buffer only on vblank. 0 = Copy SIC0OUTBUF to output buffer after writing.
2	VBCPY1	RW	0x0	Vblank copy output channel 1: See Description for SIPOLL[VBCPY0].
1	VBCPY2	RW	0x0	Vblank copy output channel 2: See Description for SIPOLL[VBCPY0].
0	VBCPY3	RW	0x0	Vblank copy output channel 3: See Description for SIPOLL[VBCPY0].

SIC0MCSR SI Communication Control Status Register
Mnemonic: SIC0MCSR
Offset: 0x34
Size: 32 bits
SIC0MCSR

Bits	Mnemonic	Type	Reset	Description
31	TCINT	RWC	0x0	Transfer Complete Interrupt Status and clear. On read this bit indicates the current status of the communication transfer complete interrupt. When a '1' is written to this Register, the interrupt is cleared. Write: 0 = No effect 1 = Transfer Complete Interrupt Read: 0 = Transfer Complete Interrupt not requested 1 = Transfer Complete Interrupt has been requested
30	TCINTMSK	RW	0x0	Transfer Complete Interrupt Mask: Interrupt masking prevents the interrupt from being sent to the main processor, but does not affect the assertion of SIC0MCSR[TCINT] 0 = Interrupt masked 1 = Interrupt enabled
29	COMERR	R	0x0	Communication Error: This indicates whether the last SI communication transfer had an error. See SiSr for the cause of the error. 0 = No error 1 = Error on transfer
28	RDSTINT	R	0x0	Read Status Interrupt Status and clear. On read this bit indicates the current status of the Read Status interrupt. The interrupt is set whenever SISR[RDSTn] bits are set. The interrupt is cleared when all of the RdSt bits in the SISR are cleared by reading from the Si Channel Input Buffers. This interrupt can be used to indicate that a polling transfer has completed and new data is captured in the input registers Read: 0 = Transfer Complete Interrupt not requested 1 = Transfer Complete Interrupt has been requested
27	RDSTINTMSK	RW	0x0	Read Status interrupt Mask: Interrupt masking prevents the interrupt from being sent to the main processor, but does not affect the assertion of SIC0MCSR[RDSTINT] 0 = Interrupt masked 1 = Interrupt enabled
26 . . . 23		R	0x0	Reserved
22 . . . 16	OUTLNTH	RW	0x0	Communication Channel Output Length in bytes. Minimum transfer is 1 byte. A value of 0x00 will transfer 128 bytes. These bits should not be modified while SICOM transfer is in progress.
15		R	0x0	Reserved

-continued

14 . . . 8	INLNTH	RW	0x0	Communication Channel Output Length in bytes. Minimum transfer is 1 byte. A value of 0x00 will transfer 128 bytes. These bits should not be modified while SICOM transfer is in progress.
2 . . . 1	CHANNEL	RW	0x0	Channel: determines which SI channel will be used the communication interface. 00 = Channel 1 01 = Channel 2 10 = Channel 3 11 = Channel 4 These bits should not be modified while SICOM transfer is in progress.
0	TSTART	RW	0x0	Transfer Start: When a '1' is written to this register, the current communication transfer is executed. The transfer begins immediately after the current transaction on this channel has completed. When read this bit represents the current transfer status. Once a communication transfer has been executed, polling will resume at the next vblank if the channel's SIPOLL[ENn] bit is set. Write: 0 = Do not start command 1 = Start command Read: 0 = Command Complete 1 = Command Pending

When programming the SICOMCSR after a SICOM transfer has already started (e.g., SICOMCSR[TSTART] is set), the example software reads the current value first, then and/or in the proper data and then writes the new data back. 30
The software should not modify any of the transfer parameters (OUTLNTH, INLNTH, CHANNEL) until the current transfer is complete. This is done to prevent a SICOM transfer already in progress from being disturbed. When writing the data back, the software should not set the 35
TSTART bit again unless the current transfer is complete and another transfer is required.

SISI SI Status Register

Mnemonic: SISR
Offset: 0x38
Size: 32 bits

SISR

Bits	Mnemonic	Type	Reset	Description
31	WR	RW	0x0	Write SICnOUTBUF Register: This register controls and indicates whether the SICnOUTBUFs have been copied to the double-buffered output buffers. This bit is cleared after the buffers have been copied. Write 1 = Copy all buffers 0 = No effect Read 1 = Buffer not copied 0 = Buffer copied
30		R	0x0	Reserved
29	RDST0	R	0x0	Read Status SIC0INBUF Register: This register indicates whether the SIC0INBUFs have been captured new data and whether the data has already been read by the main processor (read indicated by main processor read of SIC0INBUF[ERRSTAT, ERRLATCH, INPUT0, INPUT1]) 1 = New data available, not read by main processor 0 = No new data available, already read by main processor
28	WRST0	R	0x0	Write Status SIC0OUTBUF Register: This register indicates whether the SIC0OUTBUFs have been copied to the double buffered output buffers. This bit is cleared after the buffers have been copied.

-continued

				1 = Buffer not copied 0 = Buffer copied
27	NOREP0	RWC	0x0	No Response Error Channel 0: This register indicates that a previous transfer resulted in no response from the controller. This can also be used to detect whether a controller is connected. If no controller is connected, this bit will be set. Once set this bit remains set until it is cleared by the main processor. To clear this bit write '1' to this register. Write: 0 = No effect 1 = Clear No Response Error Read: 0 = No Response Error not asserted 1 = No Response Error asserted
26	COLL0	RWC	0x0	Collision Error Channel 0: This register indicates data collision between controller and main unit. Once set this bit remains set until it is cleared by the main processor. To clear this bit write '1' to this register. Write: 0 = No effect 1 = Clear Collision Error Read: 0 = Collision Error not asserted 1 = Collision Error asserted
25	OVRUN0	RWC	0x0	Over Run Error Channel 0: This register indicates that the main unit has received more data then expected. Once set this bit remains set until it is cleared by the main processor. To clear this bit write '1' to this register. Write: 0 = No effect 1 = Clear Over Run Error Read: 0 = Over Run Error not asserted 1 = Over Run Error asserted
24	UNRUN	RWC	0x0	Under Run Error Channel 0: This register indicates that the main unit has received less data then expected. Once set this bit remain set until it is cleared by the main processor. To clear this bit write '1' to this register. Write: 0 = No effect 1 = Clear Under Run Error Read: 0 = Under Run not asserted 1 = Under Run asserted
23 . . . 22		R	0x0	Reserved
21	RDST1	R	0x0	Read Status SIC1OINBUF Register: See SISR[RDST0].
20	WRST1	R	0x0	Write Status SIC0OUTBUF Register: See SISR[WRST0].
19	NOREP1	RWC	0x0	No Response Error Channel 1: See SISR[NOREP0].
18	COLL1	RWC	0x0	Collision Error Channel 1: See SISR[COLL0].
17	OVRUN1	RWC	0x0	Over Run Error Channel 1: See SISR[OVRUN0].
16	UNRUN1	RWC	0x0	Under Run Error Channel 1: See SISR[UNRUN0].
15 . . . 14		R	0x0	Reserved
13	RDST2	R	0x0	Read Status SIC1OINBUF Register: See SISR[RDST2].
12	WRST2	R	0x0	Write Status SIC0OUTBUF Register: See SISR[WRST2].
11	NOREP2	RWC	0x0	No Response Error Channel 2: See SISR[NOREP0].
10	COLL2	RWC	0x0	Collision Error Channel 2: See SISR[COLL0].
9	OVRUN2	RWC	0x0	Over Run Error Channel 2: See SISR[OVRUN0].
8	UNRUN2	RWC	0x0	Under Run Error Channel 2: See SISR[UNRUN0].
7 . . . 6		R	0x0	Reserved
5	RDST3	R	0x0	Read Status SIC1OINBUF Register: See SISR[RDST2].
4	WRST3	R	0x0	Write Status SIC0OUTBUF Register: See SISR[WRST2].
3	NOREP3	RWC	0x0	No Response Error Channel 3: See SISR[NOREP0].
2	COLL3	RWC	0x0	Collision Error Channel 3: See SISR[COLL0].
1	OVRUN3	RWC	0x0	Over Run Error Channel 3: See SISR[OVRUN0].
0	UNRUN3	RWC	0x0	Under Run Error Channel 3: See SISR[UNRUN0].

SIEXILK SI EXI Clock Lock

Mnemonic: SIEXILK

Offset: 0x3C

-continued

Bits	Mnemonic	Type	Reset	Size	Description
				32 bits SIEXILK	
31	LOCK	RW	0x1		Lock: This bit prevents the main processor from setting the EXI clock frequencies to 32 MHz. 0 = EXI Clocks Unlocked, 32 MHz EXICLK setting permitted. 1 = EXI Clock Locked, 32 MHz EXICLK setting not permitted.
30 . . . 0		R	0x0		Reserved

FIG. 8 is an even more detailed overall view of serial interface 1000. Controllers 52a and 52b (and 52c and 52d, if present) are connected to game console 54 via connector ports 1002. Modem 1404 modulates and demodulates data transferred between the controllers and the console. In the example system, communication between the console and the controllers uses duty-cycle (pulse-width) modulation and the data is communicated over one line. The communication is half-duplex. The byte transfer order is "big-endian" in which within a given multi-byte numeric representation, the most significant byte has the lowest address (i.e., the data is transferred "big-end" first). Controller input/output buffer 1016 is used for normal data transfers involving controllers 52a-52d. As shown in FIG. 8 and as will be explained in greater detail below, input/output buffer 1016 is arranged as a double buffer. Communication RAM 1014 is provided for use in variable-size data transfers to and from controllers 52a-52d. In the example system, the maximum data size of these variable-size data transfers is 32 words. Of course, the present invention is not limited in this respect. Channel selector circuit 1408 controls selectors 1412a-1412d to selectively connect modem 1404 to either communication RAM 1014 or input/output buffer 1016. An HV counter latch circuit 1406 latches the screen position of a flash signal when a trigger input is received from a light gun unit. In the example system shown in FIG. 8, triggers inputs to the HV counter latch circuit 1406 are provided for connectors 1 and 2 only. It will be apparent that trigger inputs may be provided for the other connectors if desired. HV counter latch circuit 1406 may also be used with light pens connected to connectors 1 and/or 2.

FIG. 9 shows additional details of the connections between controllers 52a-52d and serial interface 1000. The outputs of modem 1404 are supplied to controllers 52a-52d through open-drain driver buffers 1430 and the inputs from controllers 52a-52d are supplied to modem 1404 through Schmitt buffers 1432. Similarly, the outputs of controllers 52a-52d are supplied to serial interface 1000 through driver buffers 1434. The outputs to controllers 52a-52d from serial interface 1000 are supplied to controller integrated circuits (ICs) 1436.

FIG. 10 shows details of one of controllers 52. Controller 52 is connected to serial interface 1000 via a cable (not shown) about 2 meters in length in the example system. In other implementations, the communication between the controllers and the console may be over a wireless communication path such as infrared or radio frequency. Controller 52 contains an interface circuit 1504 arranged between the controller components and serial interface 1000. A button data input circuit 1502 accepts inputs from buttons disposed on an external surface of controller 52. "Buttons" as used herein refers to any device that is manipulable by a user to cause a game or other application to start, characters to

move, etc. and includes, for example, buttons, switches, joysticks, and the like. The length of the controller button and status data that is provided to serial interface 1000 is 64 bits. Vibration circuit 1506 is responsive to signals from main unit 54 via serial interface 1000 for selectively vibrating the housing of controller 52 to provide sensations to the a game player. Controller 52 also includes a 64 kbit EEPROM 1510 with a unique identifier number that is usable, for example, to store game back-up data, high game scores, etc. Controller 52 also includes a motor control system 1508 for controlling an external motor and two output ports (not shown) connectable to external components such as a motor.

Polling Via Serial Interface 1000

The input/output data size is fixed in the standard command/response packet in the example implementation. This packet is used primarily for reading data of the controllers. This data includes data indicative of which buttons are being pressed, is there a controller plugged in, the value of the analog joysticks, etc. This data is used as player input for a game (e.g., move character left/right, look up/down, fire gun, etc.). Because the polling of the controllers is performed by serial interface 1000, the workload of main processor 110 is reduced. Thus, for example, the last state of the controller 52 is in the double-buffered processor input/output register 1016 so that main processor 110 can simply read the register to determine the controller state.

An output command packet includes a 1-byte command and 2 bytes of data. With reference to the serial interface register map set forth above, SIC0OUTBUF for sending a command packet to a controller connected to connector port 1002(0), for example, includes a command byte register CMD that is an opcode for the command sent to the controller during each command/response packet. OUTPUT0 and OUTPUT1 registers are for first and second data bytes of the command packet. An input response packet includes 8 bytes of data, of which 62 bits are button data and 2 bits are controller status bits. Again with reference to the serial interface register map, SIC0INBUF (SI Channel 0 Input Buffer High) for receiving the response packet from the controller includes ERRSTAT, ERRLATCH, INPUT0, INPUT1, INPUT2 and INPUT3 registers. The ERRSTATUS bit represents the current error status for the last polling transfer on channel 0. This register is updated after each polling transfer on this channel. The ERRLATCH bit is an error status summary of the error bits for channel 0. If an error has occurred on a past transfer on channel 0 (polling or a transfer from communication RAM 1014), this bit will be set. To determine the exact error, the SISR register (see register map) may be read. The ERRLATCH bit is actually an "or" of the latched error status bits for channel 0 in the SISR. The bit is cleared by clearing the appropriate error status bits latched in the SISR. The no response error

indicates that a controller is not present on the channel. INPUT0, INPUT1, INPUT2 and INPUT3 are first through fourth data bytes of the response packet sent from controller 52 to serial interface 1000 for channel 0. In the example, implementation, the most significant two bits of INPUT0 are assumed to be "0", so they are not included in INPUT0. The fifth through eighth data bytes of the response packet are in the register SIC0INBUF (SI Channel 0 Input Buffer Low).

The characteristics of the polling of the controllers are determined in accordance with registers in SIPOLL (SI Poll Register). With reference to the register map, SIPOLL includes an X lines register and a Y times register. The X lines register determines the number of horizontal video lines between polling ("the polling interval"). The polling interval begins at the beginning of vertical blanking as shown in FIG. 12. 0x07 is the minimum setting for the X lines register as determined by the time required to complete a single polling of the controller in the example system. The maximum setting depends on the current video mode (the number of lines between vertical sync signals) and the Y times register. Of course, the invention is not limited to any particular maximum or minimum settings. The Y times register determines the number of times the controllers are polled in a single frame. This is also shown in FIG. 12.

Thus, in the controller polling process, main processor 110 writes a command to one or more of the output buffers and sets the X line and Y times registers. When main processor 110 sets one or more enable registers EN0, EN1, EN2 and EN3 of the SI Poll Register to "1", continuous polling of the corresponding controllers is started. The polling of the enabled channels is started at the same time and serial interface 1000 starts to poll at the beginning of vertical blanking and polling is repeated Y times per one frame. As noted above, the interval between pollings is determined in accordance with the setting of the X line register and the relationship between X line interval and Y times per frame is illustrated in FIG. 12. When main processor 110 sets the X line register, the Y times register and the enable register(s), controller access is started at the next vertical blanking. In the example implementation, the default setting for the Y times register is "0". Therefore, main processor 110 must set this register to use the controllers. To stop polling of a particular controller, its enable bit is set to 0; polling is stopped immediately after the current transaction.

As mentioned above, input/output buffer 1016 is actually a double buffer. The output buffer is comprised of 3 bytes for each of the four channels as described above. With reference to FIG. 8, the output data is copied from output buffer 1 to output buffer 0 of the double buffer when main processor 110 finishes writing to output buffer 1. A WR register of SISR (SI Status Register) controls and indicates whether the SICnOUTBUFs have been copied to the double buffered output buffers. The bit is set to "1" when the buffer is not yet copied and is cleared to "0" when copying is completed. Thus, if "0" is returned when main processor 110 reads WR, the copy operation is complete. If "1" is returned, the copy operation is not complete. Thus, this register must be "0" before main processor 110 writes to buffer 1. While data is transmitted from buffer 0 to the controller, copy from buffer 1 to buffer 0 is locked.

The input buffer is 8 bytes for each of the four channels and input data is copied from input buffer 0 to input buffer 1 after the controller data is received. Main processor 110 reads input buffer 1 directly per 32 bits. If new data were to be written to the low 32 bits while main processor 110 is reading the high 32 bits, the data may be incorrect.

Accordingly, when main processor 110 is reading the upper 32 bits, input buffer 1 is locked. When main processor 110 starts to read the lower 32 bits, buffer 1 is unlocked.

Ordinarily, output data is copied from buffer 1 to buffer 0 immediately after it is written to output buffer 1 by main processor 110. However, the copying may also be timed to start with vertical blanking in order to control the timing of commands to 3D LCD shutter glasses connected to display controller 164. To enable such timing, VBCPY may be set to "1" so that copies to buffer 0 occur only upon vertical blanking. The default value for the VBCPY bits is "0".

The size of the data involved in the polling is fixed. However, there are occasions on which it is desirable to transfer larger amounts of data between main console 54 and controllers 52 (e.g., writing game data to a nonvolatile memory built-in or attached to controller 52). Example serial interface 1000 provides the capability of transferring larger amounts of data in accordance with a process that is explained with reference to FIG. 11. SICOMCSR (SI Communication Control Status Register) includes a register OUTLNTH for setting the communication channel output length (in bytes); INLNTH for setting the communication channel input length (in bytes); and CHANNEL for determining which serial interface channel will be used. The minimum transfer that may be designated by OUTLNTH and INLNTH is 1 byte. A value of 0x00 will transfer 128 bytes. To transfer data, command and output data is set to communication RAM 1014 and main processor 110 sets the OUTLNTH, INLNTH and CHANNEL registers. The setting ("1") of the TSTART bit register causes execution of the current communication transfer. The transfer begins immediately after the current transaction on the designated channel is completed. When read, the TSTART bit represents the current transfer status. Once a communication transfer is executed, polling resumes at the next vertical blanking interval if the channels EN bit is set.

When main processor 110 sets the TSTART bit to "1", the transfer mode of the channel designated in the CHANNEL register is changed to Communication RAM mode by selector circuit 1408 (see FIG. 8) which controls the appropriate selector circuit to connect that channel to communication RAM 1014. In the example of FIG. 11, channel 1 is the designated channel. Output data is then transmitted from communication RAM 1014 and is output to controller 52 via modem 1404. Controller 52 may also transmit input data to channel 1 and this data is communicated to communication RAM 1014 via selector 1412a. The input data is pushed from communication RAM 1014 to main processor 110. Modem 1404 automatically clears the TSTART bit when the transfer is complete.

During Communication RAM transfer mode on channel 1, the remaining channels (i.e., channels 2, 3 and 4) continue to transfer data using input/output buffer 1016. During communication RAM transfers, main processor 110 generates an Addr CRC and transmits the CRC to the controller. The controller processes the Addr CRC to check that the data has been correctly received. In the case of a communication RAM transfer, the controller returns Data CRC. The main processor 110 generates a data CRC and compares this with the controller returned Data CRC.

FIG. 13 illustrates an example light gun connectable to connector port 1002(0) or 1002(1) of main console 54. Various types of light guns may be used and two of these types are discussed below. A first type detects a target point within one frame and generally requires that the screen and/or the target point be a bright color. A second type requires two frames to detect the target point because main

27

processor **110** flashes the screen after detection of the trigger button and starts to detect the target point at the next frame. This second type of gun typically does not require the screen to be as bright as is needed for guns of the first type. HV counter latch circuit **1406** is usable in connection with either type of light gun. The light gun includes a gun trigger **1702**. If gun trigger **1702** is pulled, a trigger signal input is transmitted for one frame. A flash signal input passing through lens **1720** is detected by a photodetector **1722**, amplified by an amplifier **1724** and supplied to logic circuit **1706** as the flash signal. Interface circuit **1704** controls whether the flash signal is passed via logic gate **1706** by controlling the signal level on the flash signal control line. If the flash signal control line is high, the flash signal is passed to HV counter latch circuit as a counter latch signal. Interface circuit **1704** controls whether the trigger signal is passed. A trigger control switch **1708** is selectively connected to power source **1710** or the trigger signal line.

In the first type of light gun, as soon as trigger **1702** is pulled, the gun starts to detect the flash signal and, if the flash signal is detected, the counter latch signal is transmitted. In the second type of light gun, when trigger **1702** is pulled, main processor **110** starts to flash the screen at the next frame. The flash signal is detected during this frame and the counter latch signal is transmitted. With a light pen, the flash signal is detected per frame and the counter latch signal is transmitted per frame.

A Gun Trigger Mode register determines the gun trigger mode and enables the counter latch register for each of channels **1** and **2**. An "always" mode is set so that the gun detects the flash signal per frame. This mode may be set for the first type of light gun and the light pen. A "1 frame" and "2 frame" mode is set so that the gun detects a flash signal for 1 or 2 frames. These modes may be set for the second type of light gun.

The HV latch counter circuit receives a counter latch signal transmitted from the light gun. In this case, the position of the flash signal is latched to the HV counter latch register. The register is shared by the 2 channels.

HV counter latch	32 bits (R)
Horizontal count	[10 . . . 0] bits
Vertical count	[20 . . . 12] bits
Field	bit 24
Counter latch signal	bit 31

FIG. **14A** depicts the output timing of the counter latch signal for the light gun of the first type. As noted above, the screen should preferably be bright for this type of light gun because the gun needs to detect a flash signal at any time. For this gun type, the trigger signal controller is always connected to the trigger side. When the trigger is pulled, flash signal detection is started. If the flash signal is detected within one frame, the counter latch signal is transmitted and the counter latch register gets the position of the flash signal. The action that results from pulling the trigger is drawn at the next frame.

FIG. **14B** depicts the output timing of the counter latch signal for the light gun of the second type. For this gun type, the trigger signal controller is always connected to the power side. When the trigger is pulled, the screen is a bright color at the next frame and flash signal detection is started. When the flash signal is detected, the counter latch signal is transmitted and the counter latch register gets the position of the flash signal. The action that results from pulling the trigger is drawn at the next frame.

28

FIG. **14C** depicts the output timing of the counter latch signal for the light pen. The screen is preferably bright for this type of light gun because the gun needs to detect a flash signal at any time. The trigger signal controller is always connected to the power side and the flash signal control line is always set to 1. The flash signal is detected per frame. The counter latch signal is transmitted and the counter latch register gets the position of the flash signal. The action that results from touching the pen on the screen is drawn at the next frame.

Example Signal Form

The signal form of the data is made up of a separation signal, a bit signal, an end signal and a continue signal.

FIG. **15(A)** depicts a separation signal that is used to distinguish the end of transmission. The separation signal is transmitted before the transmitter (main unit **54**) transmits a command and the receiver (controller **52**) distinguishes the start of the command. Thus, it is important that the receiver distinguishes this signal.

FIGS. **15(B)** and **15(C)** depict bit signals that are transmitted using the DATA line. The bit signals are duty-cycle (pulse-width) modulated as shown in FIGS. **15(B)** and **15(C)**.

FIG. **15(D)** depicts an end signal for indicating the end of the bit signal transmission. The bit signal ends by falling from high level to low level so the data line is still at low level. However, to release the data line, the transmitter must return the data line to high level. The end signal is used for this purpose.

FIG. **15(E)** depicts a continue signal used to change the direction of transmission. The transmitter returns the data line to high level and next the transmitter starts to transmit the Bit signal after a few intervals. The interval between the End signal and the Bit signal is the Continue signal. This signal is controlled by the next transmitter and is used when the receiver replies to a command of the transmitter.

Example Communication Protocol

FIGS. **16A** and **16B** depict frame units in which communication over the communication path occurs. The transmitter transmits the Command frame shown in FIG. **16A** and the receiver responds to the transmitter with a Response frame shown in FIG. **16B**. As shown in FIG. **16A**, the Command frame includes a separation signal, data and an end signal. As shown in FIG. **16B**, the Response frame includes a continue signal, data and an end signal. The data is 8-bit aligned.

Example Channel Lines

FIG. **17** depicts the lines for the channels of serial interface **1000**. A GND line is connected to a ground terminal and a PWR line connected to a VDD terminal is used to supply power from main console **54** to controller **52**. The DATA line is used to transfer data between main console **54** and controller **52**. DATA line is bi-directional and half-duplex. DATA line includes a wired-OR circuit and the transmitter pulls it to High level. The receiver may also pull it to High level. When the transmitter transmits signals, it pulls the DATA line to low level for certain times. The mechanical GND line and the mechanical PWR line are used when power is supplied to an external device coupled to the controller such as a motor. Finally, the counter latch line is used to transfer the flash signal detected from a light gun, a write pen, etc.

Other Example Compatible Implementations

Certain of the above-described system components **50** could be implemented as other than the home video game console configuration described above. For example, one could run graphics application or other software written for

system **50** on a platform with a different configuration that emulates system **50** or is otherwise compatible with it. If the other platform can successfully emulate, simulate and/or provide some or all of the hardware and software resources of system **50**, then the other platform will be able to successfully execute the software.

As one example, an emulator may provide a hardware and/or software configuration (platform) that is different from the hardware and/or software configuration (platform) of system **50**. The emulator system might include software and/or hardware components that emulate or simulate some or all of hardware and/or software components of the system for which the application software was written. For example, the emulator system could comprise a general purpose digital computer such as a personal computer, which executes a software emulator program that simulates the hardware and/or firmware of system **50**.

Some general purpose digital computers (e.g., IBM or Macintosh personal computers and compatibles) are now equipped with 3D graphics cards that provide 3D graphics pipelines compliant with DirectX or other standard 3D graphics command APIs. They may also be equipped with stereophonic sound cards that provide high quality stereophonic sound based on a standard set of sound commands. Such multimedia-hardware-equipped personal computers running emulator software may have sufficient performance to approximate the graphics and sound performance of system **50**. Emulator software controls the hardware resources on the personal computer platform to simulate the processing, 3D graphics, sound, peripheral and other capabilities of the home video game console platform for which the game programmer wrote the game software.

FIG. **18A** illustrates an example overall emulation process using a host platform **1201**, an emulator component **1303**, and a game software executable binary image provided on a storage medium **62**. Host **1201** may be a general or special purpose digital computing device such as, for example, a personal computer, a video game console, or any other platform with sufficient computing power. Emulator **1303** may be software and/or hardware that runs on host platform **1201**, and provides a real-time conversion of commands, data and other information from storage medium **62** into a form that can be processed by host **1201**. For example, emulator **1303** fetches "source" binary-image program instructions intended for execution by system **50** from storage medium **62** and converts these program instructions to a target format that can be executed or otherwise processed by host **1201**.

As one example, in the case where the software is written for execution on a platform using an IBM PowerPC or other specific processor and the host **1201** is a personal computer using a different (e.g., Intel) processor, emulator **1303** fetches one or a sequence of binary-image program instructions from storage medium **62** and converts these program instructions to one or more equivalent Intel binary-image program instructions. The emulator **1303** also fetches and/or generates graphics commands and audio commands intended for processing by the graphics and audio processor **114**, and converts these commands into a format or formats that can be processed by hardware and/or software graphics and audio processing resources available on host **1201**. As one example, emulator **1303** may convert these commands into commands that can be processed by specific graphics and/or sound hardware of the host **1201** (e.g., using standard DirectX, OpenGL and/or sound APIs).

An emulator **1303** used to provide some or all of the features of the video game system described above may also be provided with a graphic user interface (GUI) that simplifies or automates the selection of various options and screen modes for games run using the emulator. In one example, such an emulator **1303** may further include

enhanced functionality as compared with the host platform for which the software was originally intended.

FIG. **18B** illustrates an emulation host system **1201** suitable for use with emulator **1303**. System **1201** includes a processing unit **1203** and a system memory **1205**. A system bus **1207** couples various system components including system memory **1205** to processing unit **1203**. System bus **1207** may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. System memory **1207** includes read only memory (ROM) **1252** and random access memory (RAM) **1254**. A basic input/output system (BIOS) **1256**, containing the basic routines that help to transfer information between elements within personal computer system **1201**, such as during start-up, is stored in the ROM **1252**. System **1201** further includes various drives and associated computer-readable media. A hard disk drive **1209** reads from and writes to a (typically fixed) magnetic hard disk **1211**. An additional (possible optional) magnetic disk drive **1213** reads from and writes to a removable "floppy" or other magnetic disk **1215**. An optical disk drive **1217** reads from and, in some configurations, writes to a removable optical disk **1219** such as a CD ROM or other optical media. Hard disk drive **1209** and optical disk drive **1217** are connected to system bus **1207** by a hard disk drive interface **1221** and an optical drive interface **1225**, respectively. The drives and their associated computer-readable media provide nonvolatile storage of computer-readable instructions, data structures, program modules, game programs and other data for personal computer system **1201**. In other configurations, other types of computer-readable media that can store data that is accessible by a computer (e.g., magnetic cassettes, flash memory cards, digital video disks, Bernoulli cartridges, random access memories (RAMs), read only memories (ROMs) and the like) may also be used.

A number of program modules including emulator **1303** may be stored on the hard disk **1211**, removable magnetic disk **1215**, optical disk **1219** and/or the ROM **1252** and/or the RAM **1254** of system memory **1205**. Such program modules may include an operating system providing graphics and sound APIs, one or more application programs, other program modules, program data and game data. A user may enter commands and information into personal computer system **1201** through input devices such as a keyboard **1227**, pointing device **1229**, microphones, joysticks, game controllers, satellite dishes, scanners, or the like. These and other input devices can be connected to processing unit **1203** through a serial port interface **1231** that is coupled to system bus **1207**, but may be connected by other interfaces, such as a parallel port, game port Fire wire bus or a universal serial bus (USB). A monitor **1233** or other type of display device is also connected to system bus **1207** via an interface, such as a video adapter **1235**.

System **1201** may also include a modem **1154** or other network interface means for establishing communications over a network **1152** such as the Internet. Modem **1154**, which may be internal or external, is connected to system bus **123** via serial port interface **1231**. A network interface **1156** may also be provided for allowing system **1201** to communicate with a remote computing device **1150** (e.g., another system **1201**) via a local area network **1158** (or such communication may be via wide area network **1152** or other communications path such as dial-up or other communications means). System **1201** will typically include other peripheral output devices, such as printers and other standard peripheral devices.

In one example, video adapter **1235** may include a 3D graphics pipeline chip set providing fast 3D graphics rendering in response to 3D graphics commands issued based on a standard 3D graphics application programmer interface

31

such as Microsoft's DirectX 7.0 or other version. A set of stereo loudspeakers 1237 is also connected to system bus 1207 via a sound generating interface such as a conventional "sound card" providing hardware and embedded software support for generating high quality stereophonic sound based on sound commands provided by bus 1207. These hardware capabilities allow system 1201 to provide sufficient graphics and sound speed performance to play software stored in storage medium 62.

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims.

We claim:

1. A video game system, comprising:
 - a game program executing system executing a game program;
 - one or more controllers supplying user inputs to the game program executing system;
 - an interface between the controllers and the game program executing system, the interface being programmable to periodically poll the controllers without involvement of the game program executing system, wherein the interface comprises:
 - a double buffer for storing data transferred between the game program executing system and the controllers; and
 - a status register comprising one or more bits which are indicative of a status of a copy operation for copying data from one buffer to another of the double buffer.
2. The video game system according to claim 1, wherein the interface is programmable to poll the controllers a predetermined number of times between each vertical blanking interval.
3. The video game system according to claim 1, wherein the interface is programmable to poll the controllers based on a number of video lines.
4. The video game system according to claim 1, wherein the interface polls a status of the controllers.
5. The video game system according to claim 4, wherein the status of the controllers includes data indicative of player inputs.
6. The video game system according to claim 5, wherein the player inputs comprise button presses.
7. The video game system according to claim 5, wherein the player inputs comprise positions of a user manipulable joystick.
8. The video game system according to claim 4, wherein the status of the controllers includes error data.
9. The video game system according to claim 8, wherein the error data is indicative of no response from a controller in response to a transfer of data thereto.
10. The video game system according to claim 8, wherein the error data is indicative of a data collision.
11. The video game system according to claim 8, wherein the error data is indicative of the game program executing system receiving more than a predetermined amount of data from the controller.
12. The video game system according to claim 8, wherein the error data is indicative of the game program executing system receiving less than a predetermined amount of data from the controller.
13. The video game system according to claim 1, the interface further comprising:
 - selectors for selectively connecting the controllers to either the double buffer or the communication RAM.

32

14. The video game system according to claim 1, the interface further comprising:

- a modem.

15. The video game system according to claim 1, the controller including a vibration circuit for vibrating a housing of the controller.

16. The video game system according to claim 1, the controller including a read/write memory.

17. The video game system according to claim 1, further comprising:

- a communication RAM for storing data transferred between the game program executing system and the controllers.

18. The video game system according to claim 17, further comprising:

- a switching device for selectively connecting either the double buffer or the communication RAM to the controllers.

19. A video game system, comprising:

- a game program executing system executing a game program;

- a controller supplying user inputs to the game program executing system; and

- an interface interfacing between the game program executing system and the controller, the interface including communication circuitry operable in a first mode in which data of a fixed size is communicated between the game program executing system and the controller and in a second mode in which data of variable size is communicated between the game program executing system and the controller, wherein the interface further comprises:

- a communication memory for storing the variable size data;

- a double buffer for storing the fixed size data; and

- a switching device for selectively connecting either the double buffer or the communication memory to the controller.

20. The video game system according to claim 19, the interface further comprising:

- selectors for selectively connecting the controllers to either the double buffer or the communication RAM.

21. The video game system according to claim 19, the interface further comprising:

- a modem.

22. The video game system according to claim 19, further comprising:

- a status register comprising one or more bits indicative of a status of a copy operation for copying data from one buffer to another of the double buffer.

23. A video game system, comprising:

- a game program executing system having connectors connectable to one or more game controllers; and

- an interface between the connectors and the game program executing system, the interface comprising a double buffered input register and a double buffered output register corresponding to each connector, each double buffered output register comprising first and second output registers for storing data from the game program executing system for output to a controller connected thereto and each double buffered input register comprising first and second input registers for storing data from a controller connected thereto for input to the game program executing system.

24. The video game system according to claim 23, wherein copying of data from the first output register of one

33

or more of the double buffered output registers to the second output register thereof is timed to start with vertical blanking of a display connected to the video game system.

25. The video game system according to claim 23, wherein the second output registers are locked while data stored therein is output to the controllers connected thereto.

26. The video game system according to claim 23, wherein data written to the first output register from the game program executing system is copied to the second output register.

27. The video game system according to claim 23, wherein data output to each controller comprises a command packet and one or more data packets.

28. The video game system according to claim 23, wherein data input from each controller comprises input data and status data.

29. The video game system according to claim 23, wherein the interface further comprises status registers, each status register indicating a status of a copy operation for copying data from the first output register to the second output register of a corresponding double buffered output register.

30. A video game system, comprising:

a game program executing system supplied with user inputs from one or more game controllers; and

an interface between the controllers and the game program executing system, the interface comprising first and second different storage devices for storing data transferred between the game program executing system and the controllers, and selector circuitry for selectively connecting the controllers to either of the first or second storage devices.

31. The video game system according to claim 30, wherein one of the first and second storage devices is adapted for storing variable size data and the other of the first and second storage devices is adapted for storing fixed size data.

32. The video game system according to claim 30, wherein the first storage device comprises double buffered input and output registers.

33. The video game system according to claim 32, wherein output data from the game program executing system is copied from a first register of the output buffer to a second buffer of the output buffer after the output data is written to the first buffer.

34. The video game system according to claim 32, wherein input data from the controllers is copied from a first buffer of the input buffer to a second buffer of the input buffer after the input data is written to the first buffer.

35. The video game system according to claim 30, further comprising:

a modem connected to the selector circuitry.

36. A method of supplying data to a game program executing system of a video game system from controllers connected thereto, the method comprising:

receiving data from the controllers;

supplying the received data to selector circuitry;

supplying the received data from the selector circuitry to a first storage device accessible by the game program executing system if the selector circuitry is in a first state; and

supplying the received data from the selector circuitry to a different, second storage device accessible by the game program executing system if the selector circuitry is in a second state.

34

37. The method according to claim 36, wherein fixed-size data received from the controllers is supplied to the first storage device and variable-size data received from the controllers is supplied to the second storage device.

38. A method of supplying data from game program executing system of a video game system to controllers connected thereto, the method comprising:

selectively storing data from the game program executing system in first and second different storage devices connected to selector circuitry;

supplying stored data from the first storage device to the controllers if the selector circuitry is in a first state; and

supplying stored data from the second storage device to the controllers if the selector circuitry is in a second state.

39. The method according to claim 38, wherein fixed-size data from the game program executing system is stored in the first storage device and variable-size data from the game program executing system is stored in the second storage device.

40. A video game system, comprising:

a game program executing system;

a connector for connecting to a peripheral device; and

an interface between the connector and the game program executing system, the interface comprising a double buffered input register and a double buffered output register, wherein

output data from the game program executing system is copied from a first output register to a second output register of the double buffered output register after the output data is written to the first output register, and copying from the first output register to the second output register is selectively lockable, and

input data from the peripheral device is copied from a first input register to a second input register of the double buffered input register after the input data is written to the first input register, and copying from the first input register to the second input register is selectively lockable.

41. The video game system according to claim 40, wherein the interface further comprises a status register comprising one or more bits indicative of a status of a copy operation for copying data from the first output register to the second output register.

42. A video game system, comprising:

a game program executing system;

a connector for connecting to a peripheral device; and

an interface between the game program executing system and the connector, the interface comprising a first storage device for storing data of a first type which is transmitted to or received from a peripheral device connected to the connector; a different, second storage device for storing data of a second type which is transmitted to or received from a peripheral device connected to the connector; and a switching device for selectively connecting the peripheral device to either the first storage device or the second storage device.

43. The video game system according to claim 42, wherein the data of the first type is variable-size data and the data of the second type is fixed-size data.

* * * * *