

No. 26-1893

**UNITED STATES COURT OF APPEALS
FOR THE FEDERAL CIRCUIT**

COLLISION COMMUNICATIONS, INC.,

Plaintiff-Appellant,

v.

SAMSUNG ELECTRONICS CO., LTD., SAMSUNG ELECTRONICS AMERICA, INC.,

Defendants-Appellees.

Appeal from the United States District Court for the Eastern District of Texas in
No. 2:23-cv-00587-JRG, Judge J. Rodney Gilstrap

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August 4, 2026

CERTIFICATE OF INTEREST

Counsel for Appellant Collision Communications, Inc. (“Collision”) certifies the following:

1. The full name of every party represented by undersigned counsel is Collision Communications, Inc.
2. There is no other real party in interest for Collision.
3. Collision has no parent corporation and no publicly held corporation owns 10% or more of its stock.
4. The following law firms, partners, and associates appeared for Collision below or are expected to appear in this Court:

Caldwell Cassady & Curry, PC: Bailey Alexandra Blaies, Bradley Wayne Caldwell, Jason Dodd Cassady, Austin Curry, Alexander Joseph Gras, Aisha Mahmood Haley, Hamad M. Hamad, Justin Thomas Nemunaitis, James Robert Perkins (no longer with the firm), Robert Seth Reich, Jr., James F. Smith, Christopher S. Stewart, John Franklin Summers, James Yang

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5. Undersigned counsel is not aware of any pending case that may directly affect or be directly affected by this Court’s decision in this appeal.
6. This case involves no organizational victims, debtors, or trustees.

Dated: August 4, 2026

s/Paul D. Clement
Paul D. Clement

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STATEMENT OF RELATED CASES

No other appeal in or from the case below was previously before this Court or any other appellate court. Undersigned counsel is not aware of any case pending in this or any other tribunal that will directly affect or be directly affected by this Court's decision in this appeal.

INTRODUCTION

This is a paradigmatic case for a permanent injunction to prevent ongoing patent infringement. A jury found at trial that Appellant Collision Communications Inc. (“Collision”) held valid patents on inventions aimed at advanced multi-user detection receiver techniques for network-enabled devices, and that Appellees Samsung Electronics Co. Ltd. and Samsung Electronics America, Inc. (together, “Samsung”) had willfully infringed those patents. In light of that verdict, Collision moved for a narrow injunction to prohibit Samsung from continuing to infringe the one patent at issue whose term has not yet expired, by disabling the specific features in its products that the jury had found to be infringing. The undisputed record evidence shows that Samsung could comply with that proposed injunction by simply sending a software update to its existing products, without any need to recall or redesign any of its devices, and that Samsung would have no difficulty coming into compliance within the one-month grace period that the proposed injunction allows.

The district court recognized that Collision had established that it would suffer irreparable harm from Samsung’s ongoing infringement, and that monetary damages were inadequate to remedy that harm, satisfying the first two most critical elements of the traditional four-factor test for injunctive relief. But at that point, the court went inexplicably astray. Despite recognizing just a few pages earlier in its opinion that Collision would suffer irreparable harm absent an injunction, the court held that

the balance of hardships tipped against a permanent injunction—not because of any countervailing hardship to Samsung (on the contrary, the court correctly found that Samsung’s claims of hardship were unpersuasive), but simply because the court ignored the irreparable harm that Collision had already established. The court then compounded its error by holding that the public interest did not favor an injunction—again, not because the court found any countervailing public interest in maintaining the status quo, but merely because the court refused to credit the general public interest in enforcing patent rights and thereby encouraging innovation. Those errors cannot be squared with settled law and require vacating the decision below.

That suffices to resolve this appeal. But this Court can and should go farther, because the district court’s decision below exemplifies the failure of trial courts to faithfully apply the traditional equitable principles that the Supreme Court has made clear are more important than ever and must control in deciding whether to issue a permanent injunction in patent cases. Faithfully applying those principles, ongoing patent infringement itself ordinarily constitutes irreparable harm that cannot be adequately addressed by remedies at law, and so a permanent injunction will often be appropriate. The district court here failed to properly apply those traditional equitable principles. This Court should take advantage of this appeal to underscore that the district court’s analysis is at war with the Supreme Court’s approach to equitable remedies.

JURISDICTIONAL STATEMENT

The district court had jurisdiction over this patent-infringement suit under 28 U.S.C. §§1331 and 1338(a). It denied Collision’s motion for a permanent injunction on May 18, 2026. Appx25-42. Collision timely appealed on May 27, 2026. Appx2215-2217. This Court has jurisdiction under 28 U.S.C. §1292(a)(1).

STATEMENT OF THE ISSUES

Whether the district court erred as a matter of law in denying Collision a permanent injunction to prohibit Samsung from continuing to infringe.

STATEMENT OF THE CASE

A. Factual Background

1. Collision is a small start-up company founded in 2011. Appx1054-1055. Its co-founders, Stanley and Jared Fry, formed Collision after being approached by BAE Systems—a defense contractor—with a portfolio of communications technology that BAE Systems was looking to sell, which included the four patents at the heart of this dispute. Appx1055-1056. Those patents claim improvements to a technology called multiuser detection (MUD), which addresses signal interference problems that arise when smartphones, tablets, laptop computers, and other network-connected devices receive interfering signals. Appx854-855, Appx1055. That interference can prevent devices from receiving data, or increase the time required for the device to load. Appx856. That, in turn, can limit battery life, network

stability, and the usefulness of network-connected devices more generally. Appx856.

BAE Systems obtained the four patents at issue in this suit by developing improvements to allow a MUD system to cancel out or separate interfering signals. Appx858. First, patent 7,463,703 (“the ’703 patent”) addresses the “growing problem of extracting more information signals within a limited bandwidth” by disclosing a system that provides an initial amplitude estimation unit producing initial amplitude estimates; a joint amplitude estimator producing updated amplitude estimates; a symbol estimator producing a plurality of symbol estimates; and a bank of decoders that produces symbol likelihood estimates that are iteratively fed back until a final condition is met. Appx126-148. Second, patent 6,947,505 (“the ’505 patent”) discloses a system that provides real-time channel estimates of multiple interfering signals. Appx194-206. Third, patent 7,920,651 (“the ’651 patent”) discloses a joint amplitude estimator that computes individual amplitude estimates and calculates new amplitude estimates. Appx149-170. Finally, patent 7,593,492 (“the ’492 patent”), which is the patent directly at issue in this appeal, discloses a system that can be used to select a particular MUD receiver as appropriate based on certain decision criteria. Appx171-193.¹

¹ Collision initially asserted that Samsung was also infringing two other Collision patents, but its final election of claims focused on claims from the four patents

After acquiring those patents, Collision set to work on developing receiver algorithms and software to bring its groundbreaking technology to market. Of course, Collision did not intend to develop its own devices to directly compete with existing device manufacturers, which would have been a nearly impossible task for a small start-up; instead, Collision sought to provide targeted software solutions for existing communication giants like Nokia and Samsung to improve their products. Appx1058. Collision's model thus depended on achieving "design wins," to convince companies interested in licensing Collision's patented technology to work with Collision to incorporate that technology into their base stations and cellular products. Appx2069-2075. That model made it critical for a small company like Collision to be able to rely on its patent rights to protect its technology and preserve its leverage in negotiations. Appx2069-2075.

2. In the spring of 2011, Collision began negotiating a proposed deal with Samsung that would allow Samsung to deploy Collision's technology for its base stations and mobile devices. Appx1059-1060. At the outset of those negotiations, Collision gave Samsung a list of the patents that were included in Collision's portfolio. Appx1060. As Collision's co-founder, Jared Fry, explained at trial, Collision's goal was "to make it known to Samsung that we were coming to the table

described above. Appx345. Collision accordingly withdrew without prejudice its infringement claims based on the other two patents. *See* Appx697.

with real technology.” Appx1060. Samsung immediately showed interest in Collision’s patents and associated technology, including at a November 2011 meeting in Korea at which Collision’s patents were extensively analyzed and discussed. Appx1060-1061.

Naturally, Samsung was interested in running a number of tests and simulations to determine whether Collision’s technology would substantially improve the performance of Samsung’s devices. Appx1061. Collision accordingly worked hard for months to provide Samsung with all the information that it requested to demonstrate the value of Collision’s technology, and eventually traveled to Korea in 2013 to present its results to Samsung. Appx1061, Appx1064. As Collision expected and as Samsung recognized, those results “far exceeded” Samsung’s goals. Appx1064.

Impressed by the test results, Samsung “seemed like [it] wanted to move forward quickly with getting a contract in place.” Appx1064. But when Collision proposed a framework agreement under which Samsung would pay Collision a 3.5% royalty for the use of its patented technology, Samsung refused to sign; while it did not balk at the royalty fee itself, it asked instead for additional evaluations. Appx1065-1067.

In December 2013, Collision met with Samsung’s representative Sun Ja Oh, who proposed that Samsung would pay Collision a 2% royalty only on the use of

Collision's technology in macro base stations (which would have significantly reduced Collision's expected compensation). Appx1068-1069. A month later, Samsung proposed a new agreement that would have given it the right to access and use Collision's source code, and would have given Samsung (but not Collision) the right to terminate the agreement at will. Appx1070. Finally, in March 2014, after stringing Collision along for more than two years of negotiations, Samsung informed Collision that it was not interested in working with Collision after all. Appx1071. After devoting more than two years of significant effort to pursuing a deal with Samsung—during which Samsung never paid it a penny—Collision was unable to remain in business after Samsung ended the parties' negotiations, and was forced to terminate its employees and close down its research and development operations. Appx1078.

3. As the evidence at trial later showed, Samsung's decision to terminate its negotiations with Collision did not reflect Samsung's lack of interest in using Collision's patented technology; instead, it just reflected Samsung's lack of interest in paying Collision for use of that patented technology, and its decision to deliberately infringe Collision's patent rights instead. At the very same time that Ms. Oh was negotiating with Collision over a proposed framework agreement to license Collision's patented technology, she was asking Samsung's internal team to "assess the estimated ... development costs (direct expenses) that would be required

if [Samsung] were to develop this technology in house.” Appx1516. Surprised by the nature of that request, a senior researcher at Samsung responded: “If Collision successfully builds the board and demonstrates actual gains, shouldn’t we then proceed with a license agreement for technology adoption?” Appx13952. Ms. Oh replied with candor: She wanted Samsung to “estimate the level of manpower that would be required if we were to develop [Collision’s technology] ourselves,” because Collision’s proposed royalty fee was “quite substantial.” Appx13951. As far as Ms. Oh was concerned, the question was not whether Collision’s technology was useful, but only whether infringing that technology would be cheaper than licensing it—and Samsung eventually decided that infringement would be cheaper, even if it meant ignoring Collision’s patent rights.

By early 2014, Samsung had decided that it was technologically capable of implementing Collision’s patented technology on its devices without working with Collision or licensing its patents, and (mistakenly) believed that Collision would not seek to vindicate its patents. Appx1518-1519; Appx14218 (Ms. Oh reporting internally that it was “unlikely” Collision would “take legal action” against Samsung). Samsung accordingly pressed ahead with its plan to replicate Collision’s patented technology and implement it on its devices without licensing it from Collision, including by paying researchers at Korean universities to assist with its deliberate infringement. Appx1520-1522.

B. Procedural Background

After coming across a Verizon document that suggested that Samsung handsets were infringing Collision's patented technology, Collision filed this suit. Appx87-125; *see* Appx1079-1081. In its complaint, Collision alleged that Samsung was deliberately and willfully infringing Collision's patents by implementing Collision's patented technology on Samsung's devices, including its cellphones and laptops, and sought damages, a permanent injunction, an accounting, and an ongoing royalty. Appx87-125. After discovery, Samsung moved for summary judgment, which the district court denied. *See* Appx440, Appx451, Appx522. The case accordingly proceeded to trial.

At trial, Collision co-founder Jared Fry testified about the company's founding, its plan to achieve design wins by working with manufacturers like Samsung, and its initial interactions with Samsung. Appx1055, Appx1058-59, Appx1061. Mr. Fry then described the two years of extensive negotiations between Collision and Samsung, during which Collision disclosed its patent portfolio to Samsung, ran multiple tests at Samsung's request to prove the usefulness of its patented technology, and discussed a framework agreement under which Samsung would pay Collision a royalty on products that used its patented advances. Appx1060-1061, Appx1066-1067, Appx1070. Mr. Fry further testified about how Samsung had broken off its negotiations with Collision, and how Collision had

eventually learned that Samsung had been infringing Collision's patents. Appx1078-1080. Collision also presented expert testimony explaining that Samsung's products infringed all of the asserted claims of the patents-in-suit, Appx1129, Appx1132, Appx1147-1148, Appx1162, Appx1175, Appx1184-1188; that Samsung would have known as much, Appx1200; and that damages for Samsung's past infringement would reasonably amount to \$445 million, Appx1436, Appx1447-1449, Appx1453-1455.

The Samsung employees who testified at trial only bolstered Collision's case. Ms. Oh, who represented Samsung in the parties' negotiations, confirmed that Samsung had been aware of Collision's patents since 2011, that she sought to have Samsung's internal team determine the cost of developing Collision's technology in-house because Samsung wanted to have "the benefit[]" of Collision's technology "more freely," and that Samsung understood that Collision might sue it for infringement but considered that a risk worth taking. Appx1512-1514, Appx1517-1518. And Samsung's engineer Yookeun Kang confirmed that the accused features in Samsung's devices had indeed changed from 2013 to 2018, after Samsung had seen the results that Collision was able to obtain with its patented technology. Appx1590-1593. Notably, Samsung's expert was unable to identify anything else that might have prompted those changes. Appx1717-1718.

After deliberating for less than two hours, the jury found that Samsung had infringed all the asserted claims of all the asserted patents, and rejected Samsung's invalidity arguments across the board. Appx698-707. The jury found that Samsung's infringement was willful, and awarded Collision \$445 million in damages. Appx698-707. Two days later, the district court entered final judgment reflecting the jury's unanimous conclusions. Appx2038-2039.

The parties subsequently filed post-trial motions. Samsung moved for judgment as a matter of law or a new trial, suspending the time for filing a notice of appeal from the district court's judgment, *see* Fed. R. App. P. 4(a)(4); its motions have been fully briefed, and are awaiting decision by the district court. For its part, Collision moved for enhanced damages, supplemental damages, pre- and post-judgment interest, and attorneys' fees. The district court denied Collision's requests for enhanced damages and attorneys' fees, and granted in part and denied in part its requests for supplemental damages and interest.

In addition, Collision moved for a permanent injunction to prohibit Samsung from continuing to infringe the '492 patent—the only one of the patents-in-suit with any remaining term. Appx2040-2068. In patent cases as in all other cases, a plaintiff seeking a permanent injunction must show “(1) that it has suffered an irreparable injury; (2) that remedies available at law, such as monetary damages, are inadequate to compensate for that injury; (3) that, considering the balance of hardships between

the plaintiff and defendant, a remedy in equity is warranted; and (4) that the public interest would not be disserved by a permanent injunction.” *eBay Inc. v. MercExchange, LLC*, 547 U.S. 388, 391 (2006). As Collision explained in its motion, those requirements are readily met here (as in most patent cases), because under traditional equity principles the continuing infringement of a patent (like any other ongoing violation of a plaintiff’s legal rights) constitutes irreparable harm that cannot be adequately remedied by monetary damages, and requiring a defendant to stop infringing is not a cognizable hardship and serves the public interest. Appx2040-2068; *accord eBay*, 547 U.S. at 395 (Roberts, C.J., joined by Scalia and Ginsburg, JJ., concurring) (recognizing the “long tradition of equity practice” under which “[f]rom at least the early 19th century, courts have granted injunctive relief upon a finding of infringement in the vast majority of patent cases”). The United States also filed a statement of interest, in which it explained that non-practicing entities (including Collision, which was forced out of business when Samsung terminated the parties’ negotiations) can show irreparable harm and inadequate remedies at law where (as here) the patent at issue is difficult to value and damages for infringement may be difficult to calculate. Appx2095-2112.

C. The Decision Below

On May 18, 2026, the district court issued a memorandum opinion and order denying Collision’s motion for a permanent injunction. Appx25-42. The district

court found that Collision had satisfied the first two factors in the traditional four-factor test for a permanent injunction, by showing that it was suffering an irreparable injury and that monetary damages were inadequate to compensate for that injury. Appx28-36. But the court nevertheless denied Collision a permanent injunction based on the third and fourth factors, because (in the court's view) Collision had not adequately shown that the balance of hardships or the public interest favored an injunction.

1. As to the first factor, the district court began by acknowledging Collision's reliance on the "traditional principle of equity that ongoing patent infringement is irreparable harm," and did not dispute that as a historical matter courts of equity would have viewed ongoing infringement as a paradigmatic irreparable injury. Appx28-30. The district court nevertheless refused to rely on that traditional principle, on the theory that acknowledging that traditional rule would be tantamount to establishing a presumption in favor of injunctive relief in patent cases, which it viewed as inconsistent with *eBay* and its progeny. Appx29-30.

The district court nonetheless found that Collision had established irreparable harm from Samsung's ongoing infringement. Appx32-34. As the court explained, even if ongoing infringement "does not automatically entitle Collision to a finding of irreparable harm as a matter of law," a court still "properly considers ongoing infringement as a part of the irreparable harm analysis." Appx33 (emphasis

omitted). And here, Samsung’s ongoing infringement and Collision’s resulting “loss of the design-win competition”—which prevented Collision from reaping the benefits of its innovation and ultimately drove Collision out of business—was “sufficient to establish irreparable harm,” especially given “the reality that Samsung continues to use the ’492 patent against Collision’s wishes.” Appx33-34.

The court rejected Samsung’s argument that Collision could not establish irreparable harm because it had “never used its patents to sell products that would compete with Samsung’s.” Appx31. On the contrary, “a plaintiff’s ‘lack of commercial activity in practicing the patent[]’ cannot, alone, prevent a plaintiff from receiving an injunction because ‘traditional equitable principles do not permit such broad classifications.’” Appx31 (quoting *eBay*, 547 U.S. at 393). The court instead agreed with the federal government that “irreparable harm can be demonstrated by a non-practicing entity,” particularly where (as here) the “patents can be difficult to value” and the resulting “damages can be difficult to calculate.” Appx32.

2. The court next found that monetary damages were inadequate to remedy Collision’s injury from Samsung’s ongoing infringement. While the court declined to adopt the traditional equitable principle that “remedies at law are inadequate to address patent infringement,” it concluded that monetary damages would be insufficient here, given Collision’s showing of “the competitive injury it has suffered from Samsung’s infringement” and “the denial of veto-power control of its patented

technology.” Appx34-35; *see also* Appx36 (noting “the difficulty of protecting the right to exclude with money damages only”). The court rejected Samsung’s arguments that “any plaintiff which licenses its patents and does not compete with the defendant is categorically unable to show an inadequacy of monetary damages,” and that Collision had somehow “admi[tte]d that money damages are adequate” by seeking monetary damages for past infringement. Appx35-36.

3. After resolving the critical first and second factors in Collision’s favor, the district court suddenly (and inexplicably) adopted a contradictory view of the third factor. Just a few pages after recognizing Collision’s irreparable injury and the inadequacy of monetary damages as a remedy for that injury, the court claimed that Collision had “not met its burden of establishing that the balance of the hardships favors injunctive relief,” weighing against an injunction. Appx39. That was not because the court found any substantial harm to Samsung from the proposed injunction; on the contrary, the court rejected Samsung’s “conclusory statement” that a permanent injunction would “impose burdens” on its employees, explaining that “the lack of specificity Samsung has provided” made its claims of hardship “unpersuasive.” Appx37-38. The court dismissed Samsung’s arguments that an injunction would harm its customers or other third parties, as any such purported harms “are properly considered ... as part of the public interest factor” and “have no bearing on balancing the hardships *Collision and Samsung* will face if an injunction

were to be imposed.” Appx37. In any event, as the court recognized, “there is no protective shield of being ‘too big to be enjoined,’” and Samsung “cannot escape an injunction” by relying on “its status as a global commercial enterprise” to claim that an injunction would harm its employees and its customers. Appx38.

The court nevertheless concluded that Collision had failed to show that the balance of hardships weighed in its favor. Despite the extensive record evidence showing the irreparable harm to Collision from Samsung’s continued infringement—which the district court itself had recognized just a few pages earlier—the court concluded that Collision had not adequately identified “any particular or specific hardship it would face if an injunction were not to issue.” Appx38. And despite acknowledging Collision’s argument that its injunction was narrowly tailored to the specific technology that the jury had found infringes the ’492 patent, and so by definition could not impose any cognizable hardship on Samsung (since it prohibits only conduct in which Samsung has no right to engage), the district court treated the limited scope of the requested injunction as irrelevant. Appx36, Appx38-39.

4. For similar (and similarly mistaken) reasons, the district court found that Collision had not adequately shown that the public interest weighed in favor of a permanent injunction. Once again, the court did not rely on any purported harm to Samsung or other third parties in reaching that conclusion; instead, it squarely

rejected Samsung’s conclusory attempts to assert that it was “too big to be enjoined.” Appx40; *see* Appx41 (rejecting Samsung’s argument that because it is “a global corporation ... an injunction against it will always harm the public”). And the court recognized that, as Collision had argued, “[i]t is generally in the public interest to uphold and protect patent rights.” Appx41. But despite that general principle—and despite its own prior finding that allowing Samsung to continue infringing would cause Collision irreparable harm, and despite acknowledging Collision’s arguments that the injunction was narrowly tailored to prohibit only infringing conduct and that granting an injunction would “correct the behavior of parties who may prefer litigation to licensing where unpaid licensing fees might cost more than the litigation”—the court nevertheless concluded that Collision had not shown that the public interest favored granting an injunction. Appx40-41.

5. Just nine days after the district court issued its decision, Collision filed its notice of appeal. Appx2215-2217. The appeal was docketed in this Court on June 2, 2026, and Collision promptly moved on the following day to expedite the appellate proceedings, explaining that the ’429 patent expires in May 2028 and so expedition is warranted to ensure that this Court will have time to decide this appeal before the patent expires. *See* Fed. Cir. R. 27 Practice Notes (recognizing that expedition “is appropriate where the normal briefing and disposition schedule may adversely affect one of the parties, as in appeals involving preliminary or permanent

injunctions”). This Court granted Collision’s motion to expedite in part and indicated that no extensions of the briefing would be allowed and argument would be scheduled expeditiously.

SUMMARY OF ARGUMENT

The district court erred as a matter of law in denying Collision a permanent injunction against Samsung’s ongoing infringement. The court correctly found that Collision had established a likelihood of irreparable harm from that ongoing infringement, and that monetary damages would be inadequate to remedy that harm. But at that point, the district court inexplicably lost its way, concluding that Collision had not shown that either the balance of hardships or the public interest tipped in favor of an injunction—in spite of the clear (and irreparable) harm that the court had just found Collision would suffer if an injunction were denied, and the well-recognized public interest in enforcing patent rights. That decision cannot stand.

The balance of hardships in this case is clear and lopsided. As the district court itself recognized, Collision will face extensive and irreparable harm if Samsung is permitted to continue infringing its patents and thereby reap the benefits of the design wins that should have gone to Collision. And as the district court further recognized, Samsung has advanced no persuasive evidence of any cognizable hardship that it will suffer if an injunction is granted; in fact, Samsung presented no evidence (as opposed to attorney argument) at all on this point. The district court

nevertheless found the balance of hardships tipped against Collision—but only by ignoring the irreparable harm that it had already found, and rejecting the settled principle that a targeted order requiring an infringer to stop infringing is not a cognizable hardship. On both points, the district court erred as a matter of law, and absent those errors the balance of hardships strongly favors an injunction.

The district court’s analysis of the public interest was equally mistaken. The court acknowledged the well-established general public interest in enforcing patent rights in order to spur innovation—a public interest reflected in the Constitution itself—and found no countervailing public interest that would warrant denying a permanent injunction here. But the court nevertheless found that Collision had failed to satisfy the public interest factor because the public interest in enforcing patent rights exists in every patent infringement case. That is precisely backwards, and cannot be reconciled with this Court’s clear precedent, which instructs that the public interest in enforcing patents should prevail absent some countervailing public interest that outweighs it. For that reason as well, the district court’s decision must be vacated and the case remanded with instructions to grant a permanent injunction.

That suffices to resolve this appeal. But this Court can and should go farther, and correct the district court’s erroneous departure from traditional principles of equity in analyzing the irreparable harm and inadequacy of legal remedies. While the district court correctly found that both of those factors weighed in favor of a

permanent injunction here, its analysis of those factors disregarded the traditional equitable principles that the Supreme Court has emphasized as controlling in all cases, including in deciding whether a permanent injunction is warranted in a patent infringement case. Those traditional principles make clear that ongoing patent infringement ordinarily constitutes an irreparable harm that cannot be remedied by monetary damages. Those principles, which the district court cast aside, make even clearer that a permanent injunction is warranted here. This Court should take this opportunity to correct the district court's analysis on those issues, and thereby provide much-needed guidance for future cases on the proper application of traditional equitable principles in deciding whether to grant permanent injunctions in patent cases.

STANDARD OF REVIEW

This Court applies regional circuit law to issues that are not unique to patent law. *Exafer Ltd v. Microsoft Corp.*, 169 F.4th 1089, 1092 (Fed. Cir. 2026). The Fifth Circuit reviews a permanent injunction for abuse of discretion, which “occurs where the trial court (1) relies on clearly erroneous factual findings, (2) relies on erroneous conclusions of law, or (3) misapplies the factual or legal conclusions when fashioning its injunctive relief.” *Crown Castle Fiber, L.L.C. v. City of Pasadena*, 76 F.4th 425, 432-33 (5th Cir. 2023) (brackets and ellipses omitted).

ARGUMENT

I. The District Court Erred As A Matter Of Law In Denying Collision A Permanent Injunction To Prohibit Samsung From Continuing To Infringe.

The district court’s denial of Collision’s motion for a permanent injunction cannot stand. The court correctly concluded that Collision had established the first two factors of the traditional test for a permanent injunction, by showing irreparable harm from Samsung’s ongoing infringement and by showing that monetary damages were not adequate to remedy that harm. Appx28-36. But the court nevertheless denied an injunction, concluding that—despite finding that Collision was suffering ongoing and irreparable injury—Collision had failed to show that the balance of hardships and the public interest favored an injunction. That decision is as mistaken as it is puzzling, and the court erred as a matter of law in reaching it. This Court should vacate the district court’s decision and remand with instructions to grant Collision a permanent injunction.

A. The Balance of Hardships Favors a Permanent Injunction.

The third factor of the traditional test for injunctive relief looks to “the balance of hardships” between the parties. *Apple Inc. v. Samsung Elecs. Co., Ltd.*, 809 F.3d 633, 645 (Fed. Cir. 2015). That factor comes third for a reason: after a court has already evaluated whether the plaintiff has demonstrated an irreparable injury, the third factor asks the court to determine whether that irreparable injury is outweighed by any unusual hardship demonstrated by the defendant. That inquiry should have

been straightforward here. The district court itself recognized that Collision faced extensive and irreparable harm from Samsung's ongoing infringement. *See* Appx28-36; *supra* pp.13-15. And, as the district court likewise recognized, Samsung presented no evidence that it would suffer any cognizable hardship from the proposed injunction. Appx37-39. On this record, the balance of hardships tips decisively in favor of a permanent injunction, and the district court erred as a matter of law in concluding otherwise.

1. Collision will face significant hardship absent a permanent injunction.

The record here makes overwhelmingly clear that Collision will face significant hardship absent a permanent injunction. Indeed, the district court itself made that clear in its analysis of the first and second injunction factors: As the district court recognized, Collision had shown irreparable injury from Samsung's ongoing infringement and that money damages could not adequately remedy that injury, underscoring that Collision was facing and would continue to face substantial hardship in the absence of an injunction. Appx28-36. The district court then correctly and decisively rejected Samsung's effort to establish any countervailing hardship. Its conclusion that Collision nonetheless somehow came up short on the balance of hardships is inexplicable and reversible error.

As Collision explained below, Samsung's infringement prevented Collision from achieving "design wins" by demonstrating the superiority of Collision's

innovative approach as compared to existing technology, which would have opened the door for Collision to enter into co-development agreements with cellular equipment manufacturers (including Samsung) to adopt and incorporate Collision's software into their base station or handset receiver chips. Appx2069-2070. Samsung's infringement thus "deprived Collision of the competitive benefits that come from a design win—the lock-in effect, the incumbency effect, and goodwill as the winning supplier." Appx33. Absent a permanent injunction, Collision will continue to suffer the effects of that harm, as Samsung (rather than Collision) will continue to enjoy all of the benefits that it has obtained and continues to obtain from its ongoing infringement of Collision's innovative technology. That is precisely why the district court concluded that "Collision's loss of the design-win competition, taken alongside Samsung's ongoing infringement, is sufficient to establish irreparable harm in this case." Appx33-34. That irreparable harm alone is more than sufficient to show that Collision will face substantial hardship absent a permanent injunction.

But that hardship does not stand alone. As the district court recognized, denying a permanent injunction will leave in place "the reality that Samsung continues to use the '492 patent against Collision's wishes," depriving Collision of the basic "right to exclude" and "veto-power control of its patented technology" that the '492 patent grants. Appx34; *see eBay*, 547 U.S. at 395 (Roberts, C.J.,

concurring) (recognizing “the difficulty of protecting a right to *exclude* through monetary remedies that allow an infringer to *use* an invention against the patentee’s wishes”); Appx36 (acknowledging “the difficulty of protecting the right to exclude with money damages only”). And that harm is permanent: Once the patent’s limited term has expired, it cannot be extended to make up for the years that Collision has lost to Samsung’s willful and ongoing infringement. The harm that Collision will suffer from allowing Samsung to continue deliberately ignoring Collision’s basic right to exclude others from using its patented invention accordingly weighs in favor of an injunction not only as “a part of the irreparable harm analysis,” but also as part of the balance of hardships analysis, by underscoring the hardship that Collision will suffer if a permanent injunction is denied. Appx33.

The district court’s contrary conclusion—that Collision had not identified “any particular hardship it would face if the injunction were to be denied,” Appx39—is not only inexplicable, but wrong as a matter of law. The district court did not dispute that Collision had shown it would suffer substantial (indeed, irreparable) harm if Samsung were permitted to continue infringing, as that infringement would allow Samsung to continue denying Collision “the competitive benefits that come from a design win—the lock-in effect, the incumbency effect, and goodwill as the winning supplier,” as well as the basic right to exclude others from using its patented product. Appx33; *see eBay*, 547 U.S. at 395 (Roberts, C.J.,

concurring). The irreparable harm from denying Collision those ongoing benefits (which, again, the district court found for purposes of the first factor) plainly qualifies as a substantial hardship for purposes of the third factor as well. Indeed, far from dropping out of the equation, the irreparable harm found in the first factor is the principal thing that is balanced in the third factor (weighed against any hardship shown by the defendant). *See, e.g., Nippon Shinyaku Co. v. Sarepta Therapeutics, Inc.*, 25 F.4th 998, 1009 (Fed. Cir. 2022) (finding that “the balance of hardships tips in” the plaintiff’s favor in light of “the irreparable harm previously described”); *Douglas Dynamics, LLC v. Buyers Prods. Co.*, 717 F.3d 1336, 1345 (Fed. Cir. 2013) (district court “clearly erred in its balance of the hardships” by diminishing the irreparable injury it previously acknowledged).

To the extent the district court believed Collision’s showing of hardship was not “particular or specific” enough, Appx38, that runs headlong into the district court’s (and the United States’) recognition that monetary damages are inadequate here precisely because of “the unique challenges which accompany valuing patents” and the necessary imprecision involved in estimating the future value of design wins that Samsung’s infringement prevented. Appx34; *see* Appx32 (recognizing that “patents can be difficult to value” and “damages can be difficult to calculate”). The fact that Samsung’s deliberate infringement has made it impossible for Collision to precisely calculate the value that it would have gained if its patents had been

respected does not prevent Collision from showing that the balance of hardships tips decisively in favor of a permanent injunction here. Given Collision’s persuasive showing of irreparable injury, no more “particular or specific” showing of hardship was required. *Contra* Appx38.

2. Samsung will suffer no cognizable hardship from an injunction that prohibits only continued infringement.

The district court’s resolution of the balance of the hardships is truly inexplicable given that there is nothing on the other side of the ledger to outweigh Collision’s demonstrated irreparable harm, as the district court itself recognized. “The only argument Samsung ma[de] for hardship” below was the “conclusory statement” that a permanent injunction would “impose burdens” on its employees. Appx37 (emphasis omitted). The district court correctly deemed that showing “unpersuasive,” given the “lack of specificity Samsung has provided” and the absence of any actual supporting evidence—especially when Samsung faced no artificial obstacles in assembling any evidence of hardship (unlike Collision, which was prevented by Samsung’s own infringement from putting a more precise value on the future hardship it would face). Appx37-38; *see supra* pp.15-16.

In lieu of any actual evidence of hardship, Samsung declared that its “status as a global commercial enterprise” necessarily showed that it would suffer hardship from the proposed injunction. Appx38. But as the district court noted, Samsung cited “no authority stating that the size of a company can or should be a material

factor,” and there is “no protective shield of being ‘too big to be enjoined.’” Appx38. And while Samsung asserted that its employees, customers, or third parties would suffer from an injunction, those bare assertions “clearly conflate[d] a balance of hardships between the parties with the public interest factor”—and were not supported by declarations or anything of evidentiary value, instead relying solely on attorney argument. Appx37; *see Acumed LLC v. Stryker Corp.*, 551 F.3d 1323, 1330 (Fed. Cir. 2008) (recognizing that “the balance considered” under the balance-of-hardships factor “is only between a plaintiff and a defendant,” and so any effect on third parties “is irrelevant under this prong of the injunction test”).

Samsung’s inability to show any actual harm from the proposed injunction is unsurprising, as Collision sought only a targeted injunction of narrow scope. As Collision explained below (and the district court never disputed), the proposed injunction is “narrowly tailored to the specific technology found to infringe the ’492 patent,” and includes a one-month grace period to give Samsung “ample time to bring its infringement to an end.” Appx36. Because the proposed injunction is limited to prohibiting Samsung from engaging in infringing conduct, it is difficult for Samsung to establish any legitimate hardship. After all, as this Court has often explained, “[o]ne who elects to build a business on a product found to infringe cannot be heard to complain if an injunction against continuing infringement destroys the business so elected.” *Mylan Institutional LLC v. Aurobindo Pharma Ltd*, 857 F.3d

858, 865 (Fed. Cir. 2017) (quoting *Windsurfing Int’l Inc. v. AMF, Inc.*, 782 F.2d 995, 1003 (Fed. Cir. 1986)); *see, e.g., Bio-Rad Lab’ys, Inc. v. 10X Genomics, Inc.*, 967 F.3d 1353, 1378 (Fed. Cir. 2020) (recognizing that in evaluating the balance of hardships, “the consequences ... of infringement, such as the cost of redesigning the infringing products, are irrelevant” (ellipsis omitted)); *i4i Ltd. P’ship v. Microsoft Corp.*, 598 F.3d 831, 863 (Fed. Cir. 2010) (similar); *Broadcom Corp. v. Qualcomm Inc.*, 543 F.3d 683, 704 (Fed. Cir. 2008) (infringers “should not be permitted to prevail on a theory that successful exploitation of infringing technology shields a party from injunctive relief”). That settled rule reflects more than two centuries of common sense and equity practice. Courts of equity have long and consistently rejected the argument that “it will be a hardship to tie the Defendant up for ever from making” an infringing product, since “if the Plaintiffs have established their right at law, they are entitled to tie him up.” *Liardet v. Johnson* (1780) 62 Eng. Rep. 1000, 1004; 1 Y. & C.C.C. 527, 533 (Ch.).

So too here. As the record evidence shows, in the form of an uncontested expert declaration that Collision submitted along with its motion for a permanent injunction, the proposed injunction here merely requires Samsung to refrain from using the specific features covered by the ’492 patent. Appx2077-2078. Samsung could comply by simply issuing a software update for its products, a step that Samsung should have no difficulty taking within the one-month grace period that

the proposed injunction would provide. Appx2077-2079. Notably, Samsung made no attempt to present any expert declaration of its own—or any evidence *at all*—to dispute Collision’s showing that Samsung could readily comply with the proposed injunction, or to suggest that the proposed injunction would cover any technology other than the specific features that the jury found to be infringing. Because the proposed injunction “is narrowly tailored to cause no harm to Samsung other than to deprive it of the ability to continue to use [Collision’s] patented features,” the balance of hardships “strongly weighs in favor of an injunction.” *Apple*, 809 F.3d at 646.

The district court’s contrary conclusion cannot be sustained. The district court squarely rejected Samsung’s only effort to show hardship as “unpersuasive” given its “lack of specificity.” Appx37-38; *see supra* pp.15-16. That should have been fatal, as nothing cannot outweigh something and the district court already concluded that denying an injunction would cause Collision irreparable harm. Appx28-36. This Court has repeatedly found the balance of hardships to favor an injunction in comparable circumstances. *See, e.g., Oman Fasteners, LLC v. United States*, 125 F.4th 1068, 1089 (Fed. Cir. 2025) (balance of hardships favors plaintiff where the defendant “never argued ... that it would suffer any hardships”); *TEK Glob., S.R.L. v. Sealant Sys. Int’l, Inc.*, 920 F.3d 777, 793 (Fed. Cir. 2019) (balance of hardships favored a permanent injunction where the plaintiff would suffer irreparable harm,

and the defendant “ha[d] not argued that it would suffer any harm from the injunction itself”); *Abbott Labs. v. Andrx Pharms., Inc.*, 452 F.3d 1331, 1348 (Fed. Cir. 2006) (finding “little choice but to conclude that the balance of hardships favors [the plaintiff]” where the defendant was “reluctan[t] or inab[le] to quantify the hardship, if any, it will face”).

The district court also criticized Collision for invoking the traditional equitable principle that an injunction that narrowly prohibits ongoing infringement does not impose any hardship on the defendant, declaring that “tailoring Collision’s proposed injunction to the ’492 patent is no concession when enforcement of only the ’492 patent is what [Collision] seeks.” Appx36. That misses the point entirely. There are many circumstances where an injunction that the plaintiff seeks sweeps far more broadly than simply enjoining the unlawful behavior. An entire plant may need to be shuttered to enjoin a nuisance that involves only one aspect of its operations, or sales of a product may be enjoined even though only one feature is unlawful. The permissibility of such injunctions is a well-established feature of equity practice, which in turn allows a defendant to show that a proposed injunction sweeps too broadly and the balance of hardships favors the defendant. But a narrowly tailored injunction along the lines Collision proposed avoids those problems. Equity practice and this Court’s cases recognize as much. An injunction that “cause[s] no harm to [the defendant] other than to deprive it of the ability to

continue to use [the plaintiff's] patented features” does not impose any cognizable hardship on the defendant at all. *Apple*, 809 F.3d at 646; *see, e.g., Bio-Rad*, 967 F.3d at 1378 (costs imposed by prohibiting infringement “are irrelevant” to the balance-of-hardships analysis); *Liardet*, 62 Eng. Rep. at 1004. The district court made no attempt to grapple with that long-settled rule, or to explain why that rule would not control the balance-of-hardships analysis here.

Instead, the district court simply mischaracterized Collision's argument, saying that Collision was advancing a “categorical rule” that “harm to an infringing defendant is immaterial in the permanent injunction analysis.” Appx38. But Collision does not argue (and has never argued) that any and all harm to an infringing defendant is “immaterial”—a position that would make both narrow tailoring and the entire balance-of-hardships enterprise irrelevant. *Contra* Appx38. Collision has instead taken the far more modest position that under this Court's precedent and traditional equitable principles, a targeted injunction that “is narrowly tailored to cause no harm to Samsung other than to deprive it of the ability to continue to use [Collision's] patented features” causes Samsung no cognizable hardship, *Apple*, 809 F.3d at 646, because “[o]ne who elects to build a business on a product found ... to infringe cannot be heard to complain if an injunction against continuing infringement destroys the business so elected,” *Mylan*, 857 F.3d at 865. Put simply, a defendant is free to contest the balance of hardships by relying on any other

asserted harms that a proposed injunction may cause it, including hardships caused by an injunction that sweeps beyond enjoining the unlawful conduct itself, but cannot claim that the balance of hardships tips in its favor just because it will lose the benefits of the patented technology. *See Bio-Rad*, 967 F.3d at 1378; *Mylan*, 857 F.3d at 865; *Apple*, 809 F.3d at 646; *i4i*, 598 F.3d at 863; *Windsurfing*, 782 F.2d at 1003; *Liardet*, 62 Eng. Rep. at 1004; *supra* pp.27-28.

In a footnote, the district court suggested that Collision had made “inconsistent arguments” by asserting at trial that there were no adequate noninfringing alternatives to its technology, and then asserting that Samsung could readily comply with a permanent injunction. Appx39 n.2. There is no inconsistency. At trial, Collision explained that Samsung failed to identify “any non-infringing alternatives that would have allowed it to receive the same technical benefits provided by Collision’s patents.” Appx1208. But that says nothing about whether Samsung would face cognizable hardship if it is required to stop infringing. Samsung’s status quo—reaping the technical benefits of Collision’s patents—is not something that equity aims to preserve. When infringement is enjoined, it should be expected that the defendant will lose the technical benefits provided by the patented technology.

Instead, what matters for hardship is whether equity warrants giving Samsung any leeway or accommodation in bringing its infringement to an end. On that

question, Collision showed (through a declaration from its infringement expert) that Samsung could readily “disable technology that infringes the ‘492 patent” in its products through a software update, without needing to recall or radically change those products. Appx2078-2079. As the uncontested record evidence makes clear, Samsung should have no difficulty issuing that software update within the one-month grace period that the proposed injunction provides. Appx2078-2079. While Samsung’s products may lose the degree of functionality enabled by the ongoing unauthorized use of Collision’s patented technology, that is not a cognizable hardship or a reason for denying a permanent injunction. *Mylan*, 857 F.3d at 865. The district court accordingly erred as a matter of law in concluding that Collision had not shown that the balance of hardships weighs in favor of a permanent injunction here.

B. The Public Interest Favors a Permanent Injunction.

The district court likewise erred as a matter of law in evaluating the fourth factor of the permanent injunction test, which considers “the public interest.” *Apple*, 809 F.3d at 646 (quoting *eBay*, 547 U.S. at 391). Once again, this factor should have been straightforward: As this Court has often noted, the public has a “general interest in upholding patent rights,” *i4i*, 598 F.3d at 863, as public policy “favor[s] the enforcement of patent rights to promote the encouragement of investment-based risk,” *Apple*, 809 F.3d at 646; *see, e.g., ActiveVideo Networks, Inc. v. Verizon*

Commc'ns, Inc., 694 F.3d 1312, 1341 (Fed. Cir. 2012) (recognizing that “enforcing the right to exclude serves the public interest”); *Broadcom Corp.*, 543 F.3d at 704 (recognizing that “it is generally in the public interest to uphold patent rights”). And here, there is no “specific public interest” in denying an injunction that “outweighs the public’s interest in a robust patent system,” *ActiveVideo*, 694 F.3d at 1341; although Samsung asserted generally that an injunction would harm its employees, customers, and third parties, it presented no evidence whatsoever in support of those bare assertions, instead relying entirely on attorney argument. *See* Appx40. This is simply not a case where a permanent injunction would impede any “overriding public interest,” such as keeping a lifesaving product on the market. *Edwards Lifesciences AG v. CoreValve, Inc.*, 699 F.3d 1305, 1315 (Fed. Cir. 2012). Instead, the district court properly rejected Samsung’s unsupported attempt to claim that it was “too big to be enjoined,” and pointed to no other countervailing public interest here that would outweigh the general public interest in upholding patent rights. Appx40.

The district court nevertheless inexplicably concluded that Collision had not shown that “in this case, on these particular facts ... the public interest will not be disserved by an injunction.” Appx42 (emphasis omitted). The court acknowledged that “[i]t is generally in the public interest to uphold and protect patent rights,” and that the public interest favors “upholding the patent system and encouraging future

parties to negotiate with patent holders rather than to strategically infringe.” Appx41-42. But the district court then dismissed those public-interest factors favoring an injunction on the ground that they would favor an injunction in other cases of ongoing infringement, holding that Collision could not “point to a general idea that the enforcement of patent rights is usually in the public interest to meet its burden on this factor” because (in the district court’s view) that would be tantamount to a “categorical rule” that the public-interest factor should always favor the patentee. Appx41-42.

That analysis mischaracterizes Collision’s argument and defies this Court’s precedent. Collision does not argue (and has never argued) that the public interest in a strong patent system creates “a categorical rule that the public interest will *always* favor an injunction.” *Contra* Appx40. As this Court has often recognized, there may often be “other aspects of the public interest” that outweigh the general public interest in enforcing patent rights. *Apple*, 735 F.3d at 1372; *see also, e.g., ActiveVideo*, 694 F.3d at 1341 (recognizing that the “proper question on the public interest” is whether an injunction would “harm a specific public interest that outweighs the public’s interest in a robust patent system”). At the same time, the fact that the public interest in enforcing patent rights applies in every case does not justify giving that interest zero weight, or require a patentee to advance some case-specific circumstances to prove that the public interest favors an injunction “in *this*

case, on *these particular facts*.” *Contra* Appx42. Instead, as this Court has made clear, the general public interest in enforcing patent rights tips the public interest factor in favor of granting an injunction *unless* some “specific public interest” cuts in the other direction. *ActiveVideo*, 694 F.3d at 1341; *see Apple*, 735 F.3d at 1372. That approach is consistent with how courts treat other broadly applicable public interests, such as the notion that there is no public interest in government enforcement of an unconstitutional statute. *See, e.g., Texas v. Yellen*, 105 F.4th 755, 774-75 (5th Cir. 2024) (finding the public interest “clearly served” by enjoining unconstitutional laws). The district court did not identify any countervailing public interest in denying an injunction here, and erred as a matter of law in concluding that Collision could not rely on the general public interest in a strong patent system to carry its burden on this factor.

The district court also erred in discounting the “narrow and tailored” scope of the proposed injunction in evaluating the public interest. Appx41. Instead of evaluating that narrow scope, the court inexplicably asserted that “neither party addresses the steps either could take to mitigate possible public harm,” Appx41—even though Collision *did* design its proposed injunction to mitigate public harm to the greatest extent possible, by limiting the injunction to the features that the jury found to be infringing and by providing for a one-month grace period to ensure that Samsung would have adequate time to comply. *See* Appx2077-2079; *see also Apple*,

735 F.3d at 1372 (recognizing that the public-interest analysis may consider “the scope of [the] requested injunction relative to the scope of the patented features”). Those limits minimized any possible harm to any Samsung employees or customers or other third parties, allowing Samsung to continue selling all of its existing products while simply disabling the infringing features. Appx2077-2029. Indeed, if Collision had proposed a broader injunction requiring product recalls or bans on sales of a product, the resulting harm to consumers and employees would be legitimately factored into the public-interest calculus. It thus makes no sense to give no credit to Collision for narrowing the injunction to target only the infringing features or to allow the targeted nature of the injunction to just drop out of the public-interest calculus. While the fact that the proposed injunction “is narrow and tailored” may not “alone” be sufficient to show that the public interest weighs in favor of an injunction, Appx41, that fact *in conjunction with* the public interest in enforcing patent rights and the absence of any countervailing public interest here tips the public-interest factor decisively in favor of granting a permanent injunction in this case. On this record, the district court erred as a matter of law in concluding that Collision did not show that “the public interest would not be disserved by a permanent injunction.” *eBay*, 547 U.S. at 391.

II. The District Court’s Overall Approach To Traditional Equitable Principles Cannot Be Squared With Supreme Court Precedent.

The district court’s errors on the third and fourth permanent-injunction factors—which are the only two factors that the court found Collision failed to satisfy—are sufficient to require this Court to vacate the district court’s decision and remand with instructions to grant Collision a permanent injunction. But this Court can and should go further, and should also correct the district court’s mistaken approach to the traditional equitable test for permanent injunctive relief as a whole. As the Supreme Court has made clear, that test is governed by longstanding equitable principles that were well-known to the Founders, and those traditional principles continue to guide the appropriate scope for equitable relief. *See Trump v. CASA, Inc.*, 606 U.S. 831, 841 (2025). And while those traditional equitable principles do not warrant any “general rule” that a permanent injunction should issue once infringement and validity have been determined in a patent case, *eBay*, 547 U.S. at 393-94, they nevertheless make clear that a permanent injunction will often be appropriate—which is why “[f]rom at least the early 19th century, courts have granted injunctive relief upon a finding of infringement in the vast majority of patent cases,” *id.* at 395 (Roberts, C.J., concurring). The district court erred by failing to follow those traditional principles.

A. Traditional Equitable Principles Control Whether to Grant Permanent Injunctions in Patent Cases.

The federal courts have statutory authority to grant permanent injunctions in patent cases under the Judiciary Act of 1789 and under 35 U.S.C. §283, both of which authorize the federal courts to administer injunctive relief in accordance with the traditional principles of equity. Act of Sept. 24, 1789, ch. 20, §11, 1 Stat. 73, 78; *Root v. Ry. Co.*, 105 U.S. 189, 191 (1882) (reviewing acts of Congress over time giving courts authority to issue injunctive relief in patent-infringement cases). The plain text of §283 looks to the “traditions of equity practice” to determine when a permanent injunction is warranted, instructing courts to grant injunctions in patent-infringement cases according to traditional principles of equity. *Hecht Co. v. Bowles*, 321 U.S. 321, 329 (1944). And as the Supreme Court recognized in *eBay*, that statutory command remains controlling today, and requires courts to follow “the long tradition of equity practice” in deciding whether to grant permanent injunctions in patent cases. 547 U.S. at 391-92 (quoting *Weinberger v. Romero-Barcelo*, 456 U.S. 305, 320 (1982)).

As the Supreme Court has more recently underscored, the relevant traditional equitable principles date back to the Judiciary Act of 1789, which established the federal courts’ equitable jurisdiction and authority in accordance with the system of judicial remedies that the English Court of Chancery administered at the time. *CASA*, 606 U.S. at 841-42; *see, e.g., Grupo Mexicano de Desarrollo, S.A. v. Alliance*

Bond Fund, Inc., 527 U.S. 308, 319 (1999); *Payne v. Hook*, 74 U.S. (7 Wall.) 425, 430 (1869). The federal courts’ power to issue equitable remedies is therefore “the same that the High Court of Chancery in England possesse[d]” in 1789, except insofar as Congress has subsequently altered those traditional principles. *Payne*, 74 U.S. (7 Wall.) at 430.

Put simply, as the Supreme Court reaffirmed just last term, federal courts can afford only those equitable remedies “‘traditionally accorded by courts of equity’ at our country’s inception,” except to the extent Congress has expanded those remedies. *CASA*, 606 U.S. at 841 (quoting *Grupo Mexicano*, 527 U.S. at 319). Moreover, the “substantive prerequisites for obtaining an equitable remedy” have not changed since 1789. *Grupo Mexicano*, 527 U.S. at 318-19; see *Atlas Life Ins. Co. v. W.I. Southern, Inc.*, 306 U.S. 563, 568 (1939) (recognizing that the “body of doctrine which is to guide” decisions in equity is “the principles of the system of judicial remedies ... administered by the English Court of Chancery” in 1789). And if legal remedies were inadequate “when the judiciary act of 1789 was adopted,” they remain inadequate today, “unless subsequently changed by act of congress.” *McConihay v. Wright*, 121 U.S. 201, 206 (1887). The Supreme Court’s command in *eBay* that courts must exercise their discretion to grant permanent injunctions in patent cases “consistent with traditional principles of equity” therefore requires courts to consider whether a permanent injunction would have issued under

comparable circumstances in the English Court of Chancery in 1789. 547 U.S. at 394; *see, e.g., Grupo Mexicano*, 527 U.S. at 318-19.

That historical analysis provides a clear answer. At the time of the Founding, the English Court of Chancery recognized that “the ordinary relief in the case of a patent is an injunction.” *Liardet*, 62 Eng. Rep. at 1004; *see, e.g.,* 1 J. Story & A.E. Randall, *Commentaries on Equity Jurisprudence* §§930-934, at 379-80 (3d ed. 1920); 4 John Norton Pomeroy, *Equity Jurisprudence and Equitable Remedies* §§1347, 1352 (3d ed. 1905) (recognizing that “[t]he ordinary form of relief” for patent infringement is “an injunction in equity”); *see also eBay*, 547 U.S. at 395 (Roberts, C.J., concurring) (“From at least the early 19th century, courts have granted injunctive relief upon a finding of infringement in the vast majority of patent cases.”). To be clear, traditional equity practice did not make an injunction automatic or categorical relief, but there is no doubting that it was “the ordinary relief” in such cases. That is for good reason: When the four traditional equitable factors are applied as they were understood in 1789, they will ordinarily (albeit not universally or automatically) warrant a permanent injunction in patent infringement cases.

First, ongoing patent infringement—like any other ongoing trespass or violation—was traditionally recognized by equity courts in 1789 as a form of irreparable harm. *Horton v. Maltby* (1789) LI Misc MS 112, p. 10 (Ch.); *Donaldson v. Becket* (H.L. 1774), *printed in 17 The Parliamentary History of England from the*

Earliest Period to the Year 1803, at 953, 989 (William Cobbett ed., 1813). The Supreme Court has recognized this traditional principle: “When irreparable injury is spoken of, it is not meant that the injury is beyond the possibility of repair, or beyond the possibility of compensation in damages, but it must be of such constant and frequent recurrence that no fair or reasonable redress can be had therefor in a court of law.” *Donovan v. Pennsylvania Co.*, 199 U.S. 279, 305 (1905). And the Court has applied that principle specifically to patent-infringement cases. *See, e.g., Cont’l Paper Bag Co. v. E. Paper Bag Co.*, 210 U.S. 405, 430 (1908) (recognizing that “continuing wrongs and the vexation of many actions” were “well-recognized grounds of equity jurisdiction, especially in patent cases”); *see also Stearns-Roger Mfg. Co. v. Brown*, 114 F. 939, 945 (8th Cir. 1902) (affirming a preliminary injunction in a patent case due to continuing infringement); *Allington & Curtis Mfg. Co. v. Booth*, 78 F. 878, 879 (2d Cir. 1897) (affirming a preliminary injunction in a patent case because “infringement of a patent is a constantly recurring grievance”).

That settled rule followed from the broader (and well-established) continuing-violations doctrine, which held that equitable relief was appropriate to prevent ongoing or repeated violations of a plaintiff’s rights. *See, e.g., Rondeau v. Mosinee Paper Corp.*, 422 U.S. 49, 59 (1975) (discussing “the usual basis for injunctive relief, ‘that there exists some cognizable danger of recurrent violation’”) (quoting *United States v. W. T. Grant Co.*, 345 U.S. 629, 633 (1953)); *City of Walla Walla v.*

Walla Walla Water Co., 172 U.S. 1, 12 (1898) (injury is irreparable if it “is such as, from its continuance, to occasion a constantly recurring grievance”). Ongoing patent infringement was recognized as irreparable harm because courts of law could not repair it; as Justice Story explained in his *Commentaries on Equity Jurisprudence*, the irreparable harm caused by ongoing infringement was that a plaintiff could be “ruined by the necessity of perpetual litigation, without ever being able to have a final establishment of his rights.” Story & Randall, *supra*, §§930-934. Collision is now being irreparably harmed in precisely that way: Samsung’s surreptitious infringement has destroyed years of Collision’s patent term, and the legal process—litigation, trial, and now this appeal—risks destroying the remaining term.

Second, ongoing patent infringement—again, like any other ongoing trespass or violation—was traditionally seen by equity courts in 1789 as a harm that money damages are inadequate to remedy. Because common-law courts could only award damages for a “particular wrong occurring on a particular occasion,” and could not award future damages for harm that had not yet occurred, a plaintiff who prevailed in a common-law court would nevertheless be forced to file action after action against the defendant to obtain further relief if the infringement continued. *Donovan*, 199 U.S. at 305. Given that prospect of endless litigation, the continuing-violations doctrine held that remedies at law are by definition inadequate to address ongoing or repeated violations of a plaintiff’s rights; where continuing violations are

involved, “[o]nly a court of equity” can “by a comprehensive decree determine finally and once for all the entire controversy between the parties ... avoiding a multiplicity of suits, and conserving the public interests.” *Id.*; *see id.* at 304-05 (recognizing the “inadequacy of a legal remedy” in a case of “continuing trespass”); *Texas v. U.S. Dep’t of Homeland Sec.*, 123 F.4th 186, 212 (5th Cir. 2024) (“When a trespass is continuous such that stopping it would require a multiplicity of suits, an injunction is justified because monetary relief is inadequate.”). That same traditional principle likewise controlled in patent cases, where the very “nature of the [patent] right and of the wrong,” and in particular “the violation being a continuous act,” made remedies at law “necessarily inadequate.” Pomeroy, *supra*, §1352; *see Cont’l Paper Bag*, 210 U.S. at 430 (recognizing that any remedy other than an injunction “takes away the privilege which the law confers upon the patentee”). Unsurprisingly, in light of that principle, legal historians who have studied hundreds of intellectual-property cases in Chancery between 1660 and 1800 “have never encountered a case that denied a final injunction on the ground that the successful patentee had an adequate remedy at law.” H. T. Gómez-Arostegui & S. Bottomley, *The Traditional Burdens for Final Injunctions in Patent Cases c.1789 and Some Modern Implications*, 71 Case W. Res. L. Rev. 403, 414, 429 (2020).

Third, with respect to the balance of hardships, traditional equitable principles made clear (as this Court’s precedent confirms) that any hardship caused by merely

requiring the defendant to stop infringing was immaterial. Courts accordingly rejected the argument that it “will be a hardship to tie the Defendant up for ever from making” the patented product, as “if the Plaintiffs have established their right at law, they are entitled to tie him up”—a rule that “is not different from other injunctions in like cases.” *Liardet*, 62 Eng. Rep. at 1004; *see Mylan*, 857 F.3d at 865; *Bio-Rad*, 967 F.3d at 1378; *supra* pp.30-31. As noted earlier, the balance-of-hardships inquiry could be different in a case where the proposed injunction swept more broadly. *See supra* pp.30-31.

Finally, as to the fourth factor, equity traditionally viewed public-interest considerations as relevant in deciding whether to grant or deny an injunction. *See, e.g., Univs. of Oxford & Cambridge v. Richardson* (1802) 31 Eng. Rep. 1260, 1267, 1271; 6 Ves. Jun. 690, 712 (Ch.) (recognizing that “the public interest may be looked to” in deciding whether to grant an injunction, and that “nothing could be found more contrary to the interest of the public” than revoking “at a moment’s warning” letters patent granting a printing monopoly in which the printer had heavily invested). And in this country, “[t]he grant to the inventor of the special privilege of a patent monopoly carries out a public policy adopted by the Constitution and laws of the United States.” *Morton Salt Co. v. G. S. Suppiger Co.*, 314 U.S. 488, 492 (1942) (citing U.S. Const. art. I, §8, cl.8). In light of the traditional equitable principles and public policy adopted by the Constitution and laws of the United

States, the public-interest factor will often favor a permanent injunction in cases of ongoing patent infringement, at least absent any “specific public interest” in denying an injunction in a particular case, *ActiveVideo*, 694 F.3d at 1341.

In short, the Supreme Court has made clear that courts deciding whether to grant a permanent injunction in patent cases must be guided by the “long tradition of equity practice.” *eBay*, 547 U.S. at 391 (quoting *Weinberger*, 456 U.S. at 320). That tradition, and the historical understanding of the relevant equitable factors, makes clear that a permanent injunction will ordinarily be appropriate in cases involving ongoing patent infringement—which is why courts have traditionally granted that relief in “the vast majority of patent cases” for the past two centuries. *Id.* at 395 (Roberts, C.J., concurring). “[I]n this area as others, ‘a page of history is worth a volume of logic.’” *Id.* (quoting *N.Y. Tr. Co. v. Eisner*, 256 U.S. 345, 349 (1921) (Holmes, J.)).

B. The District Court Erred by Departing From Traditional Equitable Principles.

Despite the Supreme Court’s clear instruction that courts deciding whether to grant permanent injunctions in patent cases must follow “traditional equitable principles,” *eBay*, 547 U.S. at 393, the district court abused its discretion by departing from those principles. Indeed, the district court’s approach was practically the opposite of what traditional equitable considerations would require, declaring that “monetary damages have become the presumptive remedy in practice” instead

of adhering to the traditional principle that patent rights should be specifically enforced in the ordinary course. Appx27-28. This Court should not allow those errors to stand.

1. The district court departed from traditional equitable principles in evaluating irreparable harm.

First, the district court erred by disregarding traditional equitable principles in evaluating whether Collision had shown irreparable harm. While the court correctly concluded that Collision had satisfied the irreparable-harm factor, *see* Appx33-34, it should have also recognized that continued infringement will *itself* typically qualify as irreparable harm under traditional principles. As already explained, the traditional rule in 1789 was clear: Ongoing infringement of a patent (like any other ongoing violation of a plaintiff's rights) constituted irreparable harm. Story & Randall, *supra*, §§930-934; *see Cont'l Paper Bag*, 210 U.S. at 430; *Stearns-Roger*, 114 F. at 945; *Allington & Curtis*, 78 F. at 879; *see also Walla Walla*, 172 U.S. at 12; *supra* pp.41-43.

The district court nevertheless rejected that traditional approach, finding it “inconsistent with *eBay*.” Appx29. That is incorrect. *eBay* held that courts should not “categorical[ly] grant” permanent injunctions in patent cases, and rejected this Court’s “general rule” that “a permanent injunction will issue once infringement and validity have been adjudged” absent “exceptional circumstances.” 547 U.S. at 393-94. But at the same time, *eBay* made clear that courts *should* apply “traditional

principles of equity, in patent disputes no less than in other cases,” to determine when a permanent injunction is warranted. *Id.* at 394. As Chief Justice Roberts emphasized in his concurrence—joined by Justice Scalia and Justice Ginsburg—that command does not somehow cease to apply just because those traditional equitable principles will often support a finding of irreparable injury and the issuance of a targeted permanent injunction halting ongoing infringement. *Id.* at 395 (Roberts, C.J., concurring). To the contrary, the fact that “courts have granted injunctive relief upon a finding of infringement in the vast majority of patent cases” for over two centuries underscores that ongoing infringement typically satisfies the irreparable injury requirement. *Id.*

The district court’s refusal to treat ongoing patent infringement as a form of irreparable harm not only contravenes two centuries of practice in patent cases, but the continuing-violations doctrine more generally. *See supra* pp.41-43. By creating a new patent-specific rule rejecting that doctrine, the district court did precisely the opposite of what *eBay* instructs. *See* 547 U.S. at 393-94 (rejecting this Court’s adoption of a rule “unique to patent disputes”). Where, as here, traditional equitable principles provide “transsubstantive guidance on broad and fundamental questions about matters like ... remedies,” courts have no mandate to ignore those transsubstantive principles and invent their own rules for patent cases. *Romag*

Fasteners, Inc. v. Fossil, Inc., 590 U.S. 212, 217 (2020); *see eBay*, 547 U.S. at 391-94.

The district court appears to have believed that the traditional equitable principles adopted in *eBay* could not countenance treating ongoing infringement as irreparable harm “as a matter of law.” Appx29. But as the Supreme Court has often recognized, traditional equitable principles treat certain harms as irreparable as a matter of law in numerous contexts. *See, e.g., CASA*, 606 U.S. at 861 (government suffers irreparable harm as a matter of law when it is “enjoined by a court from effectuating statutes enacted by representatives of its people”); *Mahmoud v. Taylor*, 606 U.S. 522, 569 (2025) (recognizing that “loss of First Amendment freedoms, for even minimal periods of time, unquestionably constitutes irreparable injury”); *Roman Cath. Diocese of Brooklyn v. Cuomo*, 592 U.S. 14, 19 (2020) (per curiam) (same); *see also Pomeroy, supra*, §1347 (“[T]here are ... certain species of torts, in respect to each of which, as a class, it is settled that the legal remedy is generally inadequate, so that equity will generally interfere to prevent the wrong by injunction.”). There is nothing “inconsistent with *eBay*,” Appx29, let alone traditional and trans-substantive equity principles dating back to 1789, in recognizing that certain continuing violations virtually always inflict irreparable injury and render legal remedies inadequate.

The district court invoked dicta from this Court, quoting its statements that *eBay* “jettisoned the presumption of irreparable harm as it applies to determining the appropriateness of injunctive relief” and that “a successful patent infringement plaintiff can no longer rely on presumptions or other short-cuts to support a request for a permanent injunction.” Appx30 (quoting *Robert Bosch LLC v. Pylon Mfg. Corp.*, 659 F.3d 1142, 1149 (Fed. Cir. 2011)). But there is a fundamental difference between judge-made presumptions and faithfully applying traditional principles of equity. The Supreme Court is deeply skeptical of the former, *see, e.g., Halo Elecs., Inc. v. Pulse Elecs., Inc.*, 579 U.S. 93, 104-08 (2016), and affirmatively mandates the latter, *see, e.g., CASA*, 606 U.S. at 841.²

Moreover, nothing in *Bosch* suggests that district courts should ignore traditional equitable principles in applying the traditional test for a permanent injunction; on the contrary, *Bosch* explicitly reaffirms that courts must “exercise their discretion in accordance with traditional principles of equity,” and that “a page of history is worth a volume of logic” in discerning those principles. 659 F.3d at

² It bears emphasis that the statement from *Bosch* invoked by the district court is plainly non-binding dictum. Neither party in *Bosch* even invoked any presumption of irreparable harm. *See, e.g., Nat’l Am. Ins. Co. v. United States*, 498 F.3d 1301, 1306 (Fed. Cir. 2007) (“Dicta, as defined by this court, are ‘statements made by a court that are unnecessary to the decision in the case, and therefore, not precedential.’” (brackets omitted) (quoting *Co-Steel Raritan, Inc. v. Int’l Trade Comm’n*, 357 F.3d 1294, 1307 (Fed. Cir. 2004))).

1148-50. While traditional equitable principles do not create “a general rule or an effectively irrebuttable presumption that an injunction should issue,” they also cannot ignore “the fundamental nature of patents as property rights granting the owner the right to exclude,” or the traditional rule that an ongoing violation of the plaintiff’s rights constitutes irreparable harm. *Id.* at 1149-50. To the extent *Bosch* has been read more broadly, to foreclose courts from applying the traditional equitable principle that continuing infringement is a form of irreparable injury, this Court should correct that misunderstanding (and if necessary, grant *en banc* review to do so).

The district court also invoked this Court’s unpublished decision in *VidStream LLC v. Twitter, Inc.*, 2024 WL 4820802 (Fed. Cir. Nov. 19, 2024), citing it for the proposition that *eBay* “rejected” the use of any “‘broad’ and ‘categorical rule’ in deciding motions for injunctive relief in the context of patent infringement,” Appx30 (quoting *VidStream*, 2024 WL 4820802, at *1). *VidStream* is doubly irrelevant. First, the Supreme Court’s *eBay* decision speaks for itself; there is no need to seek a gloss from an unpublished and nonprecedential opinion. Fed. Cir. R. 32.1(d). And one of the things *eBay* says is that court should look to traditional principles of equity. Second, Collision does not seek a categorical rule or a burden-flipping presumption; it seeks only a recognition that traditional principles of equity dating back to 1789 and applying across different areas of the law recognize ongoing

violations as inflicting irreparable harm and rendering remedies at law inadequate. Nothing in an unpublished decision or *eBay* is an obstacle to reaffirming those principles, which the Supreme Court has only reemphasized since *VidStream* and *eBay* were decided.

2. The district court departed from traditional equitable principles in evaluating the adequacy of remedies at law.

The district court committed the same basic error in evaluating the second factor of the permanent-injunction test. While the district court correctly concluded that the second factor weighed in favor of Collision, because the harm it would suffer absent an injunction could not be adequately compensated by money damages, the court made the issue more difficult than necessary by failing to apply the traditional rule that remedies at law are necessarily insufficient to address continuing violations.

The district court did not dispute that, as described above, “traditional 18th-century equity practice makes clear that remedies at law are inadequate to address patent infringement.” Appx34 (ellipsis omitted); *see supra* pp.43-44. But it nevertheless “decline[d] to find that patent infringement cannot ever be remedied by monetary damages alone, particularly in light of the fact that the Federal Circuit has since determined the Patent Act provides courts the power to award prospective monetary relief.” Appx35 (citing *Paice LLC v. Toyota Motor Corp.*, 504 F.3d 1293, 1314 (Fed. Cir. 2007)). That conclusion was wrong for at least three reasons.

First, the ongoing-royalty remedy that *Paice* approved is an equitable remedy, not a legal remedy that might (if it were authorized by Congress) affect the adequacy-of-the-remedies-at-law inquiry. It was precisely for this reason that *Paice* concluded that there was no Seventh Amendment right to a jury trial on the amount of the royalty. *Paice*, 504 F.3d at 1315-16. Because the ongoing-royalty remedy that *Paice* recognized is equitable and not legal, its existence cannot possibly demonstrate that “remedies available at law” are now adequate and make a permanent injunction unnecessary. *eBay*, 547 U.S. at 391.

Second, even assuming *arguendo* that the ongoing-royalty remedy recognized in *Paice* qualifies as a remedy at law, it was not a legal remedy available in 1789, which is all that matters under the relevant inquiry. As the Supreme Court has explained: “The adequate remedy at law, which is the test of equitable jurisdiction in [federal] courts, is *that which existed when the judiciary act of 1789 was adopted*, unless subsequently changed by act of congress.” *McConihay*, 121 U.S. at 206 (emphasis added); *see CASA*, 606 U.S. at 842 (looking to the forms of relief “available in the High Court of Chancery in England at the time of the founding”); *supra* pp.39-40. Because the ongoing-royalty remedy that *Paice* created did not exist in 1789, and was created by the federal courts rather than by Congress, it cannot affect the second factor of the permanent-injunction test even if it were somehow considered a remedy at law.

Finally, even if the ongoing-royalty remedy recognized in *Paice* had been a remedy at law that existed in 1789, it still would not be adequate. To “exclude a concurrent remedy at equity,” an alternative remedy at law “must be as complete, as practical, and as efficient to the ends of justice and its prompt administration, as the remedy in equity.” *Walla Walla*, 172 U.S. at 12; *see Kinney-Coastal Oil Co. v. Kieffer*, 277 U.S. 488, 507 (1928) (alternative remedy at law must provide “complete relief between the parties”). The ongoing-royalty remedy recognized in *Paice* does none of that. On the contrary, by forcing a patentee to accept ongoing infringement at a price set by the court, it deprives the patentee of the “essential attribute of a patent grant”: the right to exclude others from using the patented invention. *Acumed LLC*, 551 F.3d at 1328; *see, e.g., Edwards Lifesciences AG*, 699 F.3d at 1314 (recognizing “[a] patentee’s right to exclude” as “a fundamental tenet of patent law”). Equally problematic, an ongoing royalty requires “a judicial guesstimate” of the proper royalty amount, rather than the “much preferable” approach of “negotiations between the parties” that an injunction permits. *In re Mahurkar Double Lumen Hemodialysis Catheter Pat. Litig.*, 831 F. Supp. 1354, 1397 (N.D. Ill. 1993) (Easterbrook, J., sitting by designation). And because an ongoing-royalty remedy does not take effect until final judgment, it encourages defendants to prolong litigation in order to avoid paying royalties as long as the litigation continues. An ongoing-royalty remedy therefore comes nowhere near providing “as complete, as

practical, and as efficient” a remedy as a permanent injunction. *Walla Walla*, 172 U.S. at 12. For that reason as well, the district court erred in treating the ongoing-royalty remedy recognized in *Paice* as grounds for refusing to abide by the traditional equitable rule that remedies at law are not adequate to address continuing patent infringement. To the extent that the ongoing-royalty remedy created in *Paice* has been understood as displacing the traditional equitable remedy of injunctive relief in any way, this Court should correct that misunderstanding (and if necessary, grant *en banc* review to do so). See H. Tomás Gómez-Arostegui, *Prospective Compensation in Lieu of a Final Injunction in Patent and Copyright Cases*, 78 Fordham L. Rev. 1661, 1701 (2010) (explaining how the practice of ordering ongoing royalties for future acts of infringement in lieu of granting a permanent injunction has no basis in the traditional principles of equity).

* * *

The district court erred as a matter of law in finding that Collision had failed to show that the balance of hardships and the public interest favor a permanent injunction in this case, and this Court can vacate the decision below on those grounds alone. At the same time, the decision below also offers this Court an opportunity to clarify that courts must follow traditional principles of equity in deciding whether to grant permanent injunctions in patent cases, and that those traditional principles as applied by courts of equity in 1789 will ordinarily (albeit not automatically) favor a

permanent injunction in cases of ongoing infringement. For all of those reasons, the decision below cannot stand.

CONCLUSION

This Court should vacate the decision below and remand with instructions to grant Collision a permanent injunction.

Respectfully submitted,

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August 4, 2026

CERTIFICATE OF SERVICE

I hereby certify that on August 4, 2026, I electronically filed the foregoing with the Clerk of the Court for the United States Court of Appeals for the Federal Circuit by using the CM/ECF system. I certify that all participants in this case are registered CM/ECF users and that service will be accomplished by the CM/ECF system.

s/Paul D. Clement
Paul D. Clement

CERTIFICATE OF COMPLIANCE

1. This brief complies with the type-volume limitation of Federal Circuit Rule 32(b)(1) because it contains 13,024 words, excluding the parts of the brief exempted by Federal Circuit Rule 32(b)(2).

2. This brief complies with the typeface requirements of Federal Rule of Appellate Procedure 32(a)(5) and the typestyle requirements of Federal Rule of Appellate Procedure 32(a)(6) because the brief has been prepared in a proportionally spaced typeface using Microsoft Word 2016 in 14-point Times New Roman font.

August 4, 2026

s/Paul D. Clement
Paul D. Clement

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**IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION**

COLLISION COMMUNICATIONS,
INC.,

Plaintiff,

V.

SAMSUNG ELECTRONICS CO., LTD.
and SAMSUNG ELECTRONICS
AMERICA, INC.,

Defendants.

§ § § § § § § § § § § § § § § §

CIVIL ACTION NO. 2:23-CV-00587-JRG

MEMORANDUM OPINION AND ORDER

Before the Court is the Motion for Permanent Injunction (the “Motion”) filed by Plaintiff Collision Communications, Inc. (“Collision”). (Dkt. No. 346.) Defendants Samsung Electronics Co., Ltd. and Samsung Electronics America, Inc. (“Samsung”) oppose. (Dkt. No. 357.) The United States, through the Department of Justice (“DOJ”) Antitrust Division and the United States Patent and Trademark Office (“USPTO”) filed a Statement of Interest of the United States of America (the “Statement of Interest”). (Dkt. No. 386.) The Court held a hearing regarding the Motion on May 11, 2026. (Dkt. No. 397.)

I. BACKGROUND

Collision filed the above-captioned suit against Samsung on December 12, 2023, alleging infringement of six U.S. patents. (Dkt. No. 1.) The case proceeded to trial on October 3, 2025 (Dkt. No. 307), with Collision asserting at trial infringement of four U.S. patents. (Dkt. No. 273.) On October 10, 2026, the jury returned its verdict. (Dkt. No. 313.) The jury found infringement of all asserted claims and that none of the asserted claims were invalid. (*Id.* at 4-6.) The jury further found that Samsung's infringement was willful. (*Id.* at 9.) The jury awarded damages in the form

of a reasonable royalty in the amount of \$445,494,160.00, such reasonable royalty structured as a running royalty and not a lump sum. (*Id.* at 8.) The Court entered its Final Judgment based on the verdict on November 12, 2025. (Dkt. No. 331.)

Collision filed the instant Motion on December 10, 2025, seeking to permanently enjoin Samsung from further infringement of one of the four patents-in-suit—U.S. Patent No. 7,593,492 (the “’492 patent”). (Dkt. No. 346.) The Motion is now fully briefed, including both Collision and Samsung’s responses to the DOJ and USPTO’s Statement of Interest. (*See* Dkt. Nos. 357, 370, 379, 386, 387, 388-1.) At the hearing on the Motion, Collision indicated that it is seeking injunctive relief only as to the ’492 patent because the remaining terms of the other three patents-in-suit were negligible. (Dkt. No. 397 at 5.)

II. LEGAL AUTHORITY

Congress has authorized district courts to issue injunctions “in accordance with the principles of equity to prevent the violation of any right secured by patent, on such terms as the court deems reasonable.” 35 U.S.C. § 283. The Supreme Court provided guidance in 2006 that the same generally applicable four-factor test for permanent injunctive relief must also be applied in patent cases. *See eBay Inc. v. MercExchange, L.C.C.*, 547 U.S. 388, 391 (2006). Accordingly, “a plaintiff seeking a permanent injunction... must demonstrate: (1) that it has suffered an irreparable injury; (2) that remedies available at law, such as monetary damages, are inadequate to compensate for that injury; (3) that, considering the balance of hardships between the plaintiff and defendant, a remedy in equity is warranted; and (4) that the public interest would not be disserved by a permanent injunction.” *Id.*

Prior to *eBay*, the Federal Circuit “followed the general rule that a permanent injunction will issue once infringement and validity have been adjudged, absent a sound reason to deny such

relief.” *Robert Bosch LLC v. Pylon Mfg. Corp.*, 659 F.3d 1142, 1148 (Fed. Cir. 2011) (citing *Richardson v. Suzuki Motor Co.*, 868 F.2d 1226, 1247 (Fed. Cir. 1989)).

Meanwhile, the district court which initially took up the *eBay* case applied categorical rules in the opposite direction, such as that “the evidence of the plaintiff’s willingness to license its patents, its lack of commercial activity in practicing the patents, and its comments to the media as to its intent with respect to enforcement of its patent rights, are sufficient to rebut the presumption that it will suffer irreparable harm if an injunction does not issue.” *MercExchange L.L.C. v. eBay, Inc.*, 275 F. Supp. 2d 695, 712 (E.D. Va. Aug. 6, 2003).

The Supreme Court expressly rejected both approaches in *eBay*, stating that “traditional equitable principles do not permit such broad classifications,” and that “[n]either the District Court nor the Court of Appeals below fairly applied [] traditional equitable principles in deciding [the] motion for a permanent injunction.” 547 U.S. at 393. “[T]he decision whether to grant or deny injunctive relief rests within the equitable discretion of the district courts, and [] such discretion must be exercised consistent with traditional principles of equity.” *Id.* at 394.

While nothing in *eBay* closed the door on permanent injunctions as an avenue for relief in patent cases, in the 20 years since *eBay* monetary damages have become the presumptive remedy in practice. This shift has been aided by the Federal Circuit’s determination that “awarding an ongoing royalty for patent infringement in lieu of an injunction may be appropriate.” *Paice LLC v. Toyota Motor Corp.*, 504 F.3d 1293, 1314 (Fed. Cir. 2007). In *Paice*, the Federal Circuit established that “where the district court determines that a permanent injunction is not warranted...[and] the parties fail to come to any agreement [regarding a license], the district court could step in to assess a reasonable royalty in light of the ongoing infringement.” *Id.* Such ongoing royalty has often been structured with an elevated or enhanced rate per unit in light of the knowing

nature of the continuing infringement. *See Halo Elecs., Inc. v. Pulse Elecs., Inc.*, 579 U.S. 93 (2016) (citing 35 U.S.C.A. § 284).

III. ANALYSIS

Collision asserts that injunctive relief was granted as “ordinary relief” in the English Courts of Chancery in 1789, and that “[u]nderstanding [the] factors according to how they were understood in 1789 confirms that the four-factor equitable test will typically warrant a permanent injunction in patent infringement cases.” (Dkt. No. 346 at 4, 6.) Samsung responds that such constitutes the “same argument for presumptive permanent injunctions” that *eBay* rejected. (Dkt. No. 357 at 3, 5.) The Court holds that there is **no** presumptive remedy in patent cases. Either a plaintiff seeks an injunction and shows that it meets the *eBay* test, or if not, money damages apply. In this context, the Court takes up each of the *eBay* factors as they apply in this case.

A. Irreparable Harm

Collision makes two distinct arguments as to why the Court should find it has suffered irreparable harm. It asserts both that this Court should find that ongoing patent infringement is irreparable harm as a matter of law, and that there are additional harms it has suffered which demonstrate irreparable harm “[u]nder any approach.” The Court now looks to each of these arguments, and addresses a broad assertion raised by Samsung regarding non-practicing entities.

i. Irreparable Harm as a Matter of Law

Collision asserts that “it is a traditional principle of equity that ongoing patent infringement is irreparable harm,” (Dkt. No. 346 at 6 (citing *Horton v. Maltby*, LT Misc MS 112, p. 10 (Ch. 1783))), and that “requiring a plaintiff to show something more than ongoing infringement to establish irreparable harm would be an ahistorical approach to equity” (Dkt. No. 346 at 13). It states that this Court can and should determine that “certain categories of torts,” including patent

infringement, “are irreparable harm as a matter of law,” and that “nothing in *eBay* prohibits courts from” reaching this conclusion. (*Id.* at 10.) It argues that the Federal Circuit’s opinion in *VidStream LLC v. Twitter, Inc.*—holding that a categorical rule that ongoing infringement is sufficient to establish irreparable harm is impermissible under *eBay*—should not be persuasive to this Court since it was decided before *Trump v. CASA*, “when it was perhaps less clear that the historical approach to federal equity is the governing approach.” (*Id.* at 14, citing *VidStream LLC v. Twitter, Inc.*, 2024 WL 4820802, at *1 (Fed. Cir. 2024).)

In response to the argument that Collision should be entitled to a finding of irreparable harm as a matter of law, Samsung responds that “*eBay* and its progeny [] stand for the proposition that the Federal Circuit’s prior presumption of irreparable harm in patent cases is ***inconsistent with*** traditional principles of equity.” (Dkt. No. 357 at 5 (emphasis in original).) Samsung asserts that Collision’s reading of *Trump v. CASA*, as overturning Federal Circuit opinions applying *eBay* such as *VidStream*, is “an extreme misreading of *CASA*,” which considered circumstances far removed from the permanent injunction factors in a patent case. (Dkt. No. 357 at 4.) Samsung further argues that Collision’s own evidence from British practice does not support its conclusion that ongoing patent infringement was automatically deemed irreparable harm at the final-injunction stage of litigation. (*Id.* at 7.)

The DOJ and USPTO respond to this argument from Collision as well. In the Statement of Interest, the United States urges that Collision’s position that ongoing infringement is irreparable harm as a matter of law under 18th-century principles of equity is “inconsistent with *eBay*, and the United States does not argue for such a standard.” (Dkt. No. 386 at 6 n.1.)

The Court finds that this proposed categorical rule, that ongoing infringement constitutes irreparable harm as a matter of law, is inconsistent with *eBay*. The Federal Circuit has rejected the

notion that any presumption of irreparable harm governs this inquiry. *See Robert Bosch*, 659 F.3d at 1149 (“*eBay* jettisoned the presumption of irreparable harm as it applies to determining the appropriateness of injunctive relief”); *see also VidStream*, 2024 WL 4820802, at *1 (“VidStream’s argument [that the district court had no discretion to require additional harm beyond ongoing infringement VidStream established] clearly runs afoul of the Supreme Court’s decision in [*eBay*], which rejected such a ‘broad’ and ‘categorical rule’ in deciding motions for injunctive relief in the context of patent infringement”).

As the Federal Circuit has held, “a successful patent infringement plaintiff can no longer rely on presumptions or other short-cuts to support a request for a permanent injunction.” *Robert Bosch*, 659 F.3d at 1149. The Court declines Collision’s invitation to find that *Trump v. CASA*, in stating that “a judge’s oath to follow the law” requires “[o]bserving... the boundaries of the Judiciary Act of 1789,” 606 U.S. at 858, has overturned the Federal Circuit in directly addressing the question at hand. Indeed, it would be difficult to say this Court has followed *eBay* if it were to adopt the categorical rule urged by Collision, that evidence of ongoing infringement automatically establishes irreparable harm.

As Chief Justice Roberts’ concurrence in *eBay* sets out, the “difficulty of protecting a right to *exclude* through monetary remedies that allow an infringer to *use* an invention against the patentee’s wishes... often implicates the first two factors of the traditional test.” 547 U.S. at 395 (Roberts, J., concurring). However, he goes on to state that “[t]his historical practice... does not *entitle* a patentee to a permanent injunction or justify a *general rule* that such injunctions should issue.” *Id.* Collision’s arguments for a finding of irreparable harm as a matter of law run afoul of this guidance. This Court declines to find that, in light of Samsung’s ongoing infringement, Collision is automatically entitled to a finding of irreparable harm.

ii. Irreparable Harm to Non-Practicing Entities

Samsung's first response to Collision's arguments on irreparable harm is that Collision's loss is not irreparable harm where Collision "never used its patents to sell products that would compete with Samsung's products in the same markets," and that Collision can therefore be adequately compensated via the reasonable royalty it sought. (Dkt. No. 357 at 11, citing *ActiveVideo Networks, Inc. v. Verizon Commc'ns, Inc.*, 694 F.3d 1312, 1338 (Fed. Cir. 2012).) While Samsung does not say so outright, this argument verges on an assertion that a non-practicing entity cannot establish irreparable harm.¹

It is true, as Samsung asserts, that "the Federal Circuit and courts in this District have [] held that non-practicing patent owners who license their patents but do not manufacture products rarely suffer irreparable harm from patent infringement." (Dkt. No. 357 at 12, first citing *Nichia Corp. v. Everlight Americas, Inc.*, 855 F.3d 1328, 1344 (Fed. Cir. 2017); then citing *ActiveVideo Networks*, 694 F.3d at 1338; then citing *Laserdynamics, Inc. v. Quanta Computer, Inc.*, 2010 WL 2574059, at *2 (E.D. Tex. June 22, 2010); and then citing *Fractus, S.A. v. Samsung Elecs. Co.*, 876 F.Supp.2d 802, 854 (E.D. Tex. 2012).) However, this Court rejects the position that a non-practicing entity can *never* establish irreparable harm. As the Supreme Court clearly acknowledged in *eBay*, a plaintiff's "lack of commercial activity in practicing the patents" cannot, alone, prevent a plaintiff from receiving an injunction because "traditional equitable principles do not permit such broad classifications." 547 U.S. at 393. Samsung's posture all but invites the Court to go down the path of another impermissible bright-line rule. The Court declines such invitation.

Further, a party's status as non-practicing entity can be a transient one. Any currently non-

¹ While Samsung admitted, in its oral argument, that a non-practicing entity could suffer irreparable harm in certain (unexplained) circumstances (*see, e.g.*, Dkt. No. 397 at 82-83), the differences between their briefing and their argument persuade the Court of a need to address this matter.

practicing entity may have once practiced its patents, and may choose to do so again (or for the first time) in the future. The entity may pursue patent assertion as a means of raising the capital needed to convert its operations (or return to its operation) to practicing its patents. To be clear, there are not “two classes” of patents. A non-practicing entity holds patents with the same rights as that of any practicing patent owner. The identity of the patent holder does not impact the rights conferred by the patent granted.

The Supreme Court has long recognized that the rights of a patent holder are equivalent to the rights an owner holds in any other form of property when it comes to the owner’s right to use, **or not use**, the property as they see fit. *See, e.g., Cont’l Paper Bag Co. v. E. Paper Bag Co.*, 210 U.S. 405, 429 (1908) (“[I]t is the privilege of any owner of property to use or not use it, without question of motive”). To differentiate between patent owners based on (non)use would be to create a lower second class of patent ownership, implying different and lesser rights. This distinction is not supported by the text of any statute, any decision of the Supreme Court, or any practice by the USPTO. The USPTO does not issue patents with a gold seal if the holder practices the patents, but issues patents with only a silver seal when they do not.

Indeed, the USPTO urges in the Statement of Interest that a non-practicing patentee can demonstrate irreparable harm under certain circumstances. (Dkt. No. 386 at 7.) In particular, the Statement of Interest puts forth that irreparable harm can be demonstrated by a non-practicing entity given that (1) patents can be difficult to value and (2) damages can be difficult to calculate. (*Id.* at 8-10.) The USPTO is correct in this regard.

iii. Additional Bases for Irreparable Harm

Collision further asserts it has suffered irreparable harm because it has “been denied veto-power control of its patented technology,” and because Samsung’s infringement caused

competitive injury in the “design-win” competition it was engaged in with Samsung’s in-house team, and thus “deprived Collision of the competitive benefits that come from a design win—the lock-in effect, the incumbency effect, and goodwill as the winning supplier.” (Dkt. No. 346 at 15-18.) At the hearing, Collision clarified that it was “trying to... enter different technology companies’ technology stacks. They want their designs to be incorporated into whoever they’re talking to’s product. In this case, it is Samsung.” (Dkt. No. 397 at 27.) Collision asserts that it lost out on this “great validation for Collision” because of Samsung’s infringement. (*Id.*)

Further, the Court properly considers ongoing infringement as a part of the irreparable harm analysis, despite its finding that such ongoing infringement does not *automatically* entitle Collision to a finding of irreparable harm as a matter of law.

Responding more directly to Collision’s additional bases for irreparable harm, Samsung asserts that Collision’s arguments about “design-win” competition are flawed. Samsung argues this point fails both because of Jared Fry’s trial testimony, which attributed Collision’s business struggles to *Nokia* (not Samsung) losing interest in collaborating with Collision, and because an injunction is forward-looking relief which requires a plaintiff to show they will be harmed in the *future*. (Dkt. No. 357 at 12, citing *Murthy v. Missouri*, 603 U.S. 43, 58 (2024).) Samsung additionally argues that the Federal Circuit’s holdings regarding irreparable harm in design win competitions relate to situations where the plaintiff competed with the defendant in the same market for goods using the patent, which is inapplicable since Collision does not compete with Samsung. (Dkt. No. 357 at 13.) Samsung finally asserts that Collision’s delay in filing suit, where (according to Samsung) Collision had constructive notice of the infringement by 2015 and did not seek relief until 2023, “shows that the harm it claims is not irreparable.” (*Id.* at 14-15.)

The Court finds that Collision’s loss of the design-win competition, taken alongside

Samsung's ongoing infringement, is sufficient to establish irreparable harm in this case. The Court considers the totality of the circumstances in reaching its conclusion. The Court also notes the struggle incumbent on any patent holder in protecting the right to exclude and the reality that Samsung continues to use the '492 patent against Collision's wishes. *See eBay*, 547 U.S. at 395 (acknowledging "the difficulty of protecting a right to *exclude* through monetary remedies that allow an infringer to *use* an invention against the patentee's wishes") (Roberts, J., concurring) (emphasis in original).

Accordingly, the Court finds that Collision has established that it has suffered irreparable harm in this case as required for injunctive relief to issue under *eBay*.

B. Adequacy of Monetary Damages

Collision urges the same arguments (as for irreparable harm) to assert that monetary damages are inadequate to compensate for its injury in this case. Collision again posits that "traditional 18th-century equity practice makes clear that... remedies at law are inadequate to address patent infringement." (Dkt. No. 346 at 15.) Collision further asserts that the denial of veto-power control of its patented technology, and the competitive injury it has suffered from Samsung's infringement, also cannot be remedied by monetary damages. (*Id.* at 15-16.)

The United States similarly urges the same points as it highlighted for irreparable harm, that monetary damages may be inadequate due to the unique challenges which accompany valuing patents and determining monetary damages for infringement. (Dkt. No. 386 at 8-10.)

In response to Collision's arguments about traditional equity practice, Samsung argues that such cases are inapplicable given that "[p]atent practice is different today"—namely, the Federal Circuit now permits both an ongoing royalty for patent infringement in lieu of an injunction, and damages that reflect future use of the patent by the defendant. (Dkt. No. 357 at 8, first citing *Paice*.,

504 F.3d at 1314; and then citing *Trans-World Mfg. Corp. v. Al Nyman & Sons, Inc.*, 750 F.2d 1552, 1565 (Fed. Cir. 1985).) Accordingly, “[a]lthough money damages for future injury were non-existent, and thus inadequate, at Chancery, they exist and are adequate today. So Chancery’s presumption of inadequacy does not apply.” (Dkt. No. 357 at 8.) Samsung further asserts that “[a] plaintiff like Collision that has consistently sought (and received) money for patent licenses cannot argue that money will be insufficient to remedy any infringement,” and that monetary damages are sufficient to remedy Collision’s claims of design-win losses as well. (*Id.* at 16.) This argument, however, presupposes that if money damages have been adequate in the past, they will be again in the present case. This argument is unavailing.

The Court declines to find that patent infringement cannot ever be remedied by monetary damages alone, particularly in light of the fact that the Federal Circuit has since determined the Patent Act provides courts the power to award prospective monetary relief. *See Paice*, 504 F.3d at 1314. Similarly, the Court declines to follow Samsung’s suggested rule that *any* plaintiff which licenses its patents and does not compete with the defendant is categorically unable to show an inadequacy of monetary damages. *See, e.g., eBay*, 547 U.S. at 393 (“[T]raditional equitable principles do not permit such broad classifications,” as “a ‘plaintiff’s willingness to license its patents’ ... would be sufficient to establish that the patent holder would not suffer irreparable harm if the injunction did not issue”). Additionally, a plaintiff’s ability to seek enhanced monetary damages, as provided for in Section 284 of the Patent Act, in and of itself does not mean the same plaintiff would not be entitled to injunctive relief.

The Court is aware that Collision brought this action seeking money damages as a remedy for past harms. Its First Amended Complaint seeks injunctive relief, as well, and presumptively, for future damages. (*See* Dkt. No. 76.) Collision also sought the potential enhancement of those

damages through their evidence of willfulness. Nothing in Collision’s pleadings rises to the level of an admission that money damages are adequate in this case. As with the first *eBay* factor, this Court pays close heed to Chief Justice Roberts when he notes the difficulty of protecting the right to exclude with money damages only. *eBay*, 547 at 395. The Chief Justice also cites with approval the advice of Justice Holmes about understanding and properly applying these equitable standards by noting, “a page of history is worth a volume of logic.” *Id.* (quoting *New York Tr. Co. v. Eisner*, 256 U.S. 345, 349 (1921) (opinion for the Court by Holmes, J.)). While the Court also acknowledges the warning in Justice Kennedy’s *eBay* concurrence that new forms of commerce and business practices might not always square with the *volume of logic* Justice Holmes referenced, the historical underpinnings of the injunction as an equitable remedy in patent cases must not be ignored or swept away. Considering the totality of the record, the briefing, and the oral arguments, the Court concludes that Collision has demonstrated it meets this factor.

C. Balance of Hardships

Collision asserts that any hardship to Samsung from complying with a permanent injunction is immaterial under traditional principles of equity. (Dkt. No. 346 at 18 (citing *Liardet v. Johnson* (Ch. 1780) (“[As to the argument] that it will be a hardship to tie the Defendant up for ever from making this [infringing product],... if the Plaintiffs have established their Right at Law, they are intitled to tie him up”).) Collision further asserts that their proposed injunction is “narrowly tailored to the specific technology found to infringe the ’492 patent,” and that the one-month grace period Collision proposes the injunction include would “give[] Samsung ample time to bring its infringement to an end.” (Dkt. No. 346 at 18.) However, tailoring Collision’s proposed injunction to the ’492 patent is no concession when enforcement of only the ’492 patent is what the Motion seeks.

Samsung responds that Collision has presented two historical cases, which reach opposite conclusions on whether a defendant’s hardship is material, and that “[s]uch limiting and conflicting Founding-era authority does not provide any basis to depart from the mandatory traditional rule that the defendant’s hardship is considered in granting permanent injunctions—much less a basis to ignore Supreme Court precedent” requiring the consideration of a balance of the hardships. (Dkt. No. 357 at 9, citing *eBay*, 547 U.S. at 391.) Samsung then asserts that imposing a permanent injunction in this case would pose severe hardships to thousands of its employees, both in the United States and abroad, that an injunction would “significantly disrupt related third-party businesses like Samsung’s suppliers, customers, and retail sellers” by “depriv[ing them] of the benefit of their contracts with Samsung,” and that customers would suffer from the limitation on consumer choice in the phone market an injunction would create. (Dkt. No. 357 at 17.)

However, the Court notes that Samsung’s arguments on this factor clearly conflate a balance of the hardships between the parties with the public interest factor. Samsung’s assertions that customers and third parties would suffer if an injunction were to be imposed are properly considered by the Court as part of the public interest factor. They have no bearing on balancing the hardships *Collision and Samsung* will face if an injunction were to be imposed.

Regarding Samsung’s employee arguments, Samsung seems to suggest that the mere scale of its operations means the Court should not issue an injunction against it. Samsung asserts that it “has close to 20,000 full-time employees in the United States alone, ... [and] ‘assembly plants and sales networks in 88 countries and employes around 370,000 people.’” (Dkt. No. 357 at 17 (internal citation omitted).) The only argument Samsung makes for hardship *it* will face (as opposed to hardship its customers and third-parties will face), is the conclusory statement that “Collision’s broad proposed order would ***impose burdens*** on each of those employees in each of

those countries.” (*Id.* (emphasis added).) However, Samsung’s employees are not Samsung the corporate entity. The Court also finds these arguments unpersuasive, given both the lack of specificity Samsung has provided as well as the fact that they do not apply to Samsung as an *entity*.

The Federal Circuit has expressly held, regarding this factor, that “[a] party cannot escape an injunction simply because it is smaller than the patentee or because its primary product is an infringing one.” *Robert Bosch*, 659 F.3d at 1156. It stands to reason that the reverse is true as well. Samsung cannot avoid *ever* being enjoined because of its status as a global commercial enterprise. It points to no authority stating that the size of a company can or should be a material factor. For global companies like Samsung, there is no protective shield of being “too big to be enjoined,” any more than there is a statutory shield of being “too big to fail” in the global financial sector. As the Federal Circuit’s analysis in *Robert Bosch* demonstrates, the hardship each party alleges, and the appropriate balance to be struck between them, is to be assessed in the context of that party’s circumstances and relationship to the harm stemming from either the granting or denial of an injunction.

However, Collision’s briefing on this point is similarly deficient. Collision makes the conclusory argument that Samsung will not suffer any hardship. In its oral argument, Collision acts as though its bearing the brunt of the hardships is *a fait accompli*. (*See* Dkt. No. 379.) It then makes no effort to identify any particular or specific hardship it would face if an injunction were not to issue. (*See* Dkt. No. 346 at 18.)

Given the Supreme Court expressly instructs in *eBay* for courts to “consider[] the balance of hardships between plaintiff and defendant,” 547 U.S. at 391, the Court declines Collision’s invitation to adopt another categorical rule—that harm to an infringing defendant is immaterial in the permanent injunction analysis—which would essentially remove this factor from the Court’s

consideration.

At the hearing on the Motion, Collision urged that “the hardship factor is largely going to be satisfied by having an injunction that is narrowly tailored to the infringement,” and that Collision believes “Samsung could comply with this injunction.” (Dkt. No. 397 at 23, 43.) Samsung rightly emphasized that Collision bears the burden on this factor. (*Id.* at 69.) It then argued such burden has not been met by Collision. (*Id.*)

The Court finds that both sides have made a rather poor showing on this issue. The lack of mutual specifics leave the Court little to go on. While Collision argues its proposed injunction is narrow and tailored, it must still meet its burden to show the balance of hardships between the parties falls on it. Ultimately, the burden is on the *plaintiff* to show that a remedy in equity is warranted considering the balance of the parties’ hardships. *See eBay*, 547 U.S. at 391. Accordingly, the Court finds that Collision has not met its burden of establishing that the balance of the hardships favors injunctive relief, in light of its failure to identify any particular hardship it would face if the injunction were to be denied, and its bare assertions that Samsung would have no issue complying with the proposed “tailored” injunction. The hardships each would bear must be identified clearly and then compared fairly. Collision makes an argument that this factor can be “largely satisfied” by considering only the breadth and scope of the injunction it has proposed—but again, there is no presumption that Collision is entitled to relief or can automatically meet this factor through any showing other than a showing of the relative hardships between the parties.²

² In addition, Collision has made inconsistent arguments from trial to now in how necessary this technology is to Samsung and whether there are any alternatives. Samsung represented at the hearing that to date it has not successfully identified noninfringing alternatives to using this technology (where Collision argued at trial, to support its damages figure, that there are not adequate noninfringing alternatives in the market). (Dkt. No. 397 at 75-78.) It is insufficient for Collision to now make the bare assertion that the injunction is “narrowly tailored... and so imposes no cognizable harm on Samsung,” as it “does not require Samsung to develop new single-user MIMO algorithms; rather, it would only require Samsung to limit its existing single user MIMO algorithms to a non-infringing subset.” (Dkt. No. 346 at 18.) Collision cannot assert at trial that there are no noninfringing alternatives, and now succeed based on the conclusory suggestion that Samsung can easily operate around the injunction.

cost more than the litigation.³ Similarly, Samsung returns to its earlier argument that it is a global corporation such that an injunction against it will always harm the public unduly. Unfortunately, neither party addresses the steps either could take to mitigate possible public harm. However, the “touchstone of the public interest factor is whether an injunction, both in scope and effect, strikes a *workable balance* between protecting the patentee’s rights and protecting the public from the injunction’s adverse effects.” *i4i Ltd. P’ship v. Microsoft Corp.*, 598 F.3d 831, 863 (Fed. Cir. 2010) (emphasis added). Let this Court be clear, neither party is entitled to the categorical rule they each seek.

It is generally in the public interest to uphold and protect patent rights, but the burden nevertheless remains on a plaintiff “to show that the public interest would be better served though an injunction under the circumstances of *this* case.” *Laserdynamics*, 2010 WL 2574059, at *3 (emphasis added). The burden is clearly on Collision to demonstrate “that that the public interest would not be *disserved* by a permanent injunction.” *eBay*, 547 U.S. at 391 (emphasis added). Collision stating that its own proposed injunction is narrow and tailored, alone, is not sufficient.

At the hearing, Collision pointed to the power of an injunction to “correct” the fact that “Samsung assum[ed] it ha[d] the right to take [Collision’s] technology... [by] forc[ing] Samsung to confront the reality of having to live without someone else’s technology.” (Dkt. No. 397 at 30.)

³ Taking this argument together with Collision’s previous assertions regarding irreparable harm and monetary damages being established as a matter of law, and the argument that harm to Samsung is immaterial in this analysis, Collision signals itself to be seeking a return to the Federal Circuit’s pre-*eBay* practice of near-automatic injunctions once infringement is found. In particular, earlier in its brief Collision asserts that “injunctive relief should be ordinary relief in patent-infringement cases in U.S. federal courts today. ‘Ordinary’ does not mean automatic. Injunctions could still be denied for public interest reasons.” (Dkt. No. 346 at 5.) It seems to be Collision’s position that the public interest factor is the only area where courts should do in-depth analysis—yet in its public interest section, Collision argues that private licensing negotiations between the parties (which an injunction would force) are “[an] outcome [that is] superior **in every case**.” (*Id.* at 19 (emphasis added).) While the Court has already declined to adopt Collision’s position that ongoing infringement constitutes irreparable harm as a matter of law, it is worth noting the line Collision wrongly attempts to draw in the sand that the public interest consideration is the only factor that could potentially limit an injunction in a case of ongoing infringement, and yet the public interest factor will (per Collision) also always favor injunctive relief. Collision’s briefing seems to say, “Heads I win, tails you lose.”

Similar to its analysis on the balance of the hardships factor, the Court finds that Collision cannot point to a general idea that the enforcement of patent rights is usually in the public interest to meet its burden on this factor. Collision has made no showing that in *this* case, on *these particular facts*, the importance of upholding the patent system and encouraging future parties to negotiate with patent holders rather than to strategically infringe meets its burden to show that the public interest will not be disserved by an injunction. The Court does not find that Collision has met its burden on this factor.

IV. CONCLUSION

For the reasons stated herein, the Court finds that Collision has not met each of the four factors required to establish it is entitled to injunctive relief under *eBay* in this case. Accordingly, the Court finds that Collision's Motion for Permanent Injunction should be and hereby is **DENIED**.

So Ordered this

May 17, 2026



RODNEY GILSTRAP
UNITED STATES DISTRICT JUDGE

(12) **United States Patent**
Lande

(10) **Patent No.: US 7,593,492 B1**
 (45) **Date of Patent: Sep. 22, 2009**

(54) **COMBINATIONAL HYBRID TURBO-MUD**

(75) Inventor: **Mark Lande**, Nashua, NH (US)

(73) Assignee: **BAE Systems Information and Electronic Systems Integration Inc.**, Nashua, NH (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 623 days.

(21) Appl. No.: **11/532,125**

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(51) **Int. Cl.**
H03D 1/04 (2006.01)

(52) **U.S. Cl.** **375/346; 375/148; 370/342**

(58) **Field of Classification Search** 375/144, 375/148, 341, 346; 370/342, 441
 See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,506,861	A	4/1996	Bottomley	
5,563,897	A	10/1996	Pyndiah et al.	
6,122,269	A	9/2000	Wales	
6,151,370	A	11/2000	Wei	
6,167,022	A	12/2000	Ishida et al.	
6,182,261	B1	1/2001	Haller et al.	
6,704,376	B2	3/2004	Mills et al.	
6,898,248	B1	5/2005	Elgamal et al.	
7,110,439	B2 *	9/2006	MacLeod	375/147
7,133,433	B2 *	11/2006	Jalloul et al.	375/141
7,340,281	B2 *	3/2008	Zeira et al.	455/562.1
2003/0187928	A1	10/2003	MacLeod et al.	
2004/0022336	A1	2/2004	Yu et al.	
2005/0018793	A1	1/2005	Learned	

OTHER PUBLICATIONS

Pottie, Gregory J et al., "A Comparison of Reduced Complexity Decoding Algorithms for Trellis Codes", IEEE on Selected Areas in Communications, Dec. 1989, pp. 1369-1380, vol. 7, No. 9.

Berrou, Claude et al., "Near Optimum Error Correcting Coding and Decoding: Turbo-Codes", IEEE Trans. on Communications, Oct. 1996, pp. 1261-1271, vol. 44, No. 10.

Berrou, Claude et al., "Near Shannon Limit Error-Correcting Coding and Decoding: Turbo Codes(1)", IEEE, 1993, pp. 1064-1070.

Duanyi, Wang et al., "Low-Complexity MAP Decoding for Turbo Codes", Vehicular Technology Conference, 2000, pp. 1035-1039, Princeton University, Princeton NJ.

Herzog, Rupert et al., "Iterative Decoding and Despreading Improves CDMA-Systems Using M-ary Orthogonal Modulation and FEC", IEEE, 1997, pp. 909-913.

Das, Suman et al., "Computationally Efficient Iterative Multiuser Detection and Decoding", Asilomar, 1998, pp. 631-634, Department of Electrical and Computer Engineering, Rice University, Houston Texas.

Wang, Xiaodong et al., "Iterative (Turbo) Soft Interference Cancellation and Decoding for Coded CDMA", IEEE Trans. on Communications, Jul. 1999, pp. 1046-1061, vol. 47, No. 7.

Poor, Vincent, "Turbo Multiuser Detection: An Overview", Department of Electrical Engineering, IEEE 6th International Symposium on Spread-Spectrum Tech. & Appliances, Sep. 2000, pp. 583-587, Princeton University, Princeton NJ.

(Continued)

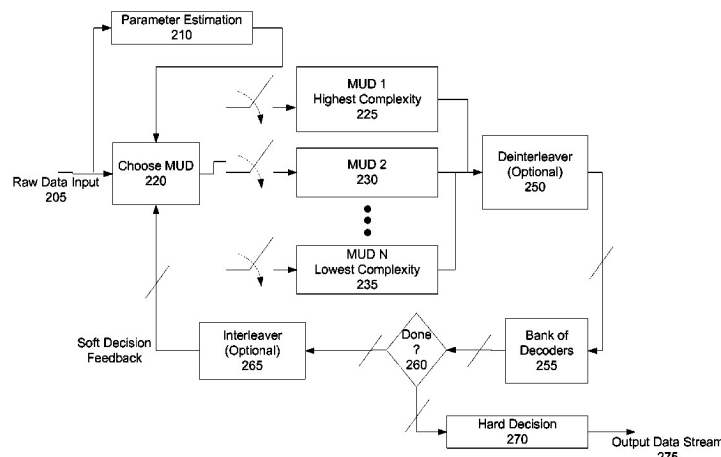
Primary Examiner—Kevin Y Kim

(74) *Attorney, Agent, or Firm*—Vern Maine & Associates

(57) **ABSTRACT**

A high quality real-time Turbo-Mud processing system that chooses between a high complexity multi-user detectors that results in better estimates of the bit streams and computationally low linear-based-MUD/Turbo-MUD at each MUD window in each Turbo Iteration. In one embodiment this technique optimizes both the BER and the computational complexity of the receiver by using low complexity MUDs to reduce the number of symbols that the high complexity MUDs need to process. The present invention also provides an efficient means of estimating symbols transmitted in a multi-user environment in overloaded or super-saturated conditions.

20 Claims, 7 Drawing Sheets



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OTHER PUBLICATIONS

- Alexander, Paul et al., "Iterative Multiuser Interference Reduction: Turbo CDMA", IEEE Transactions on Communications, Jul. 1999, pp. 1008-1014, vol. 47, No. 7.
- Hagenauer, Joachim et al., "A Viterbi Algorithm with Soft-Detection Outputs and its Applications", IEEE, 1989, pp. 1680-1686.
- Robertson, Patrick, "A Comparison of Optimal and Sub-Optimal MAP Decoding Algorithms Operating in the Log Domain", IEEE, 1995, pp. 1009-1013.
- Verdu, S., "Minimum Probability of Error for Asynchronous Gaussian Multiple-Access Channels", IEEE Transactions on Information Theory, Jan. 1986, pp. 85-96, vol. IT-32, No. 1.
- Lupas, Ruxandra et al., "Linear Multiuser Detectors for Synchronous Code-Division Multiple-Access Channels", IEEE Transactions on Information Theory, Jan. 1989, pp. 123-136, vol. 35, No. 1.

- Wei, Lei et al., "Synchronous DS-SSMA System with Improved Decorrelating Decision-Feedback Multiuser Detection", IEEE Transactions on Vehicular Technology, Aug. 1994, pp. 767-772, vol. 43, No. 3.
- Varanasi, Mahesh K. et al., "Near-Optimum Detection in Synchronous Code-Division Multiple-Access Systems", IEEE Transactions on Communications, May 1991, pp. 725-736, vol. 39, No. 5.
- Duel-Hallen, Alexandra, "Decorrelating Decision-Feedback Multiuser Detector for Synchronous Code-Division Multiple-Access Channel", IEEE Transactions on Communications, Feb. 1993, pp. 285-290, vol. 41, No. 2.
- Lupas, Ruxandra et al., "Near-Far Resistance of Multiuser Detectors in Asynchronous Channels", IEEE Transactions on Communications, Apr. 1990, pp. 496-508, vol. 38, No. 4.

* cited by examiner

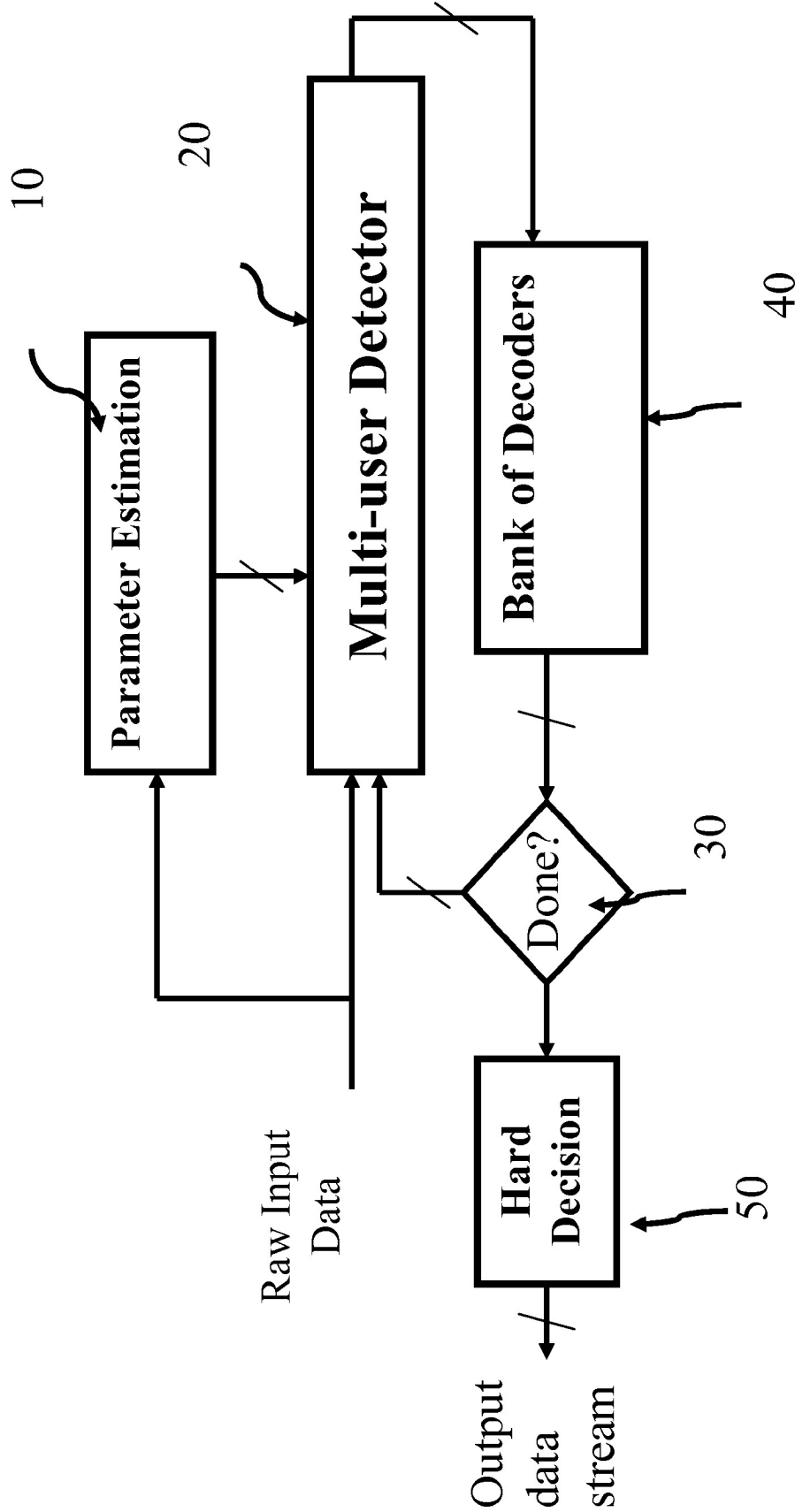


Figure 1
(Prior Art)

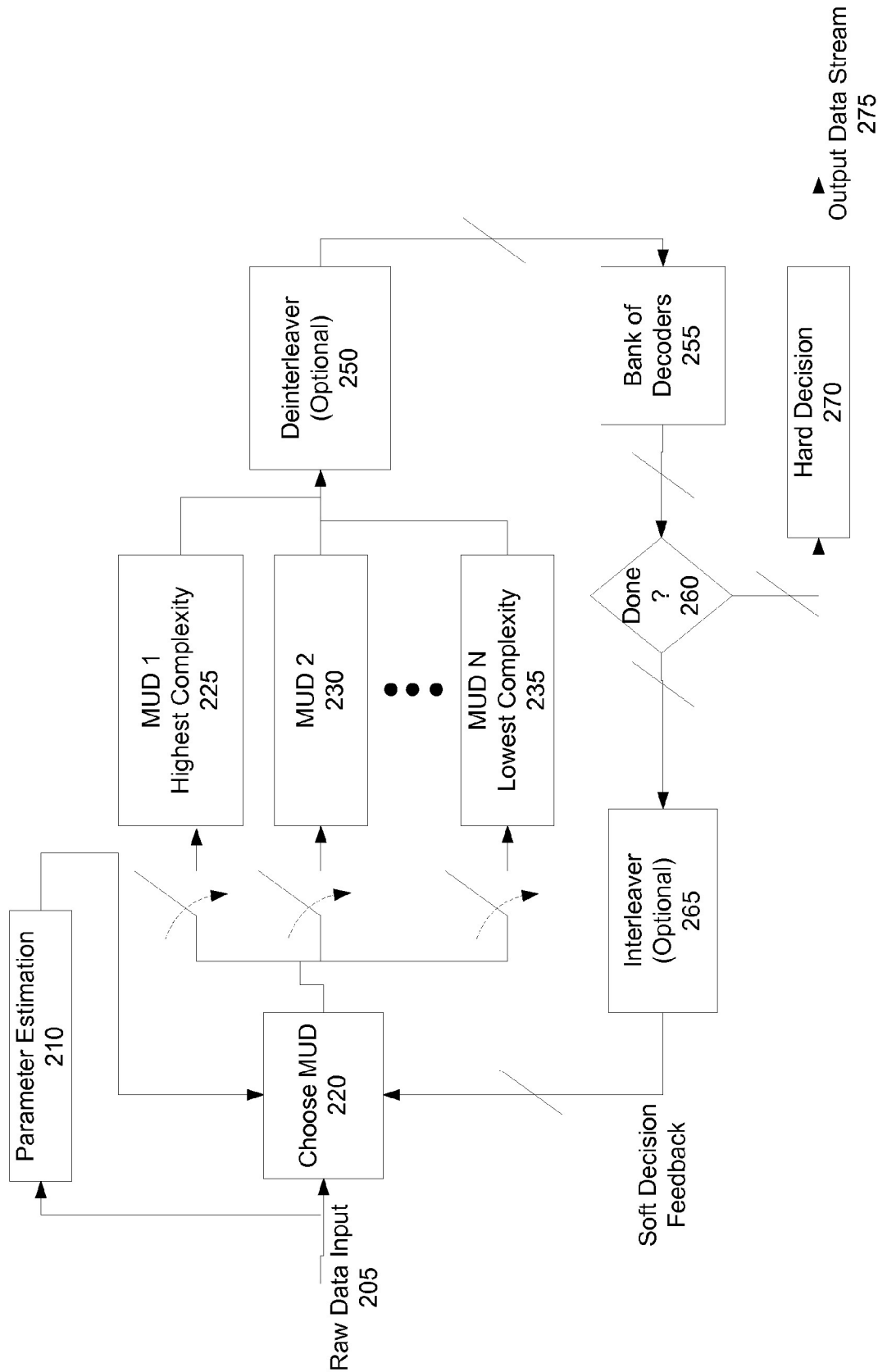


Figure 2

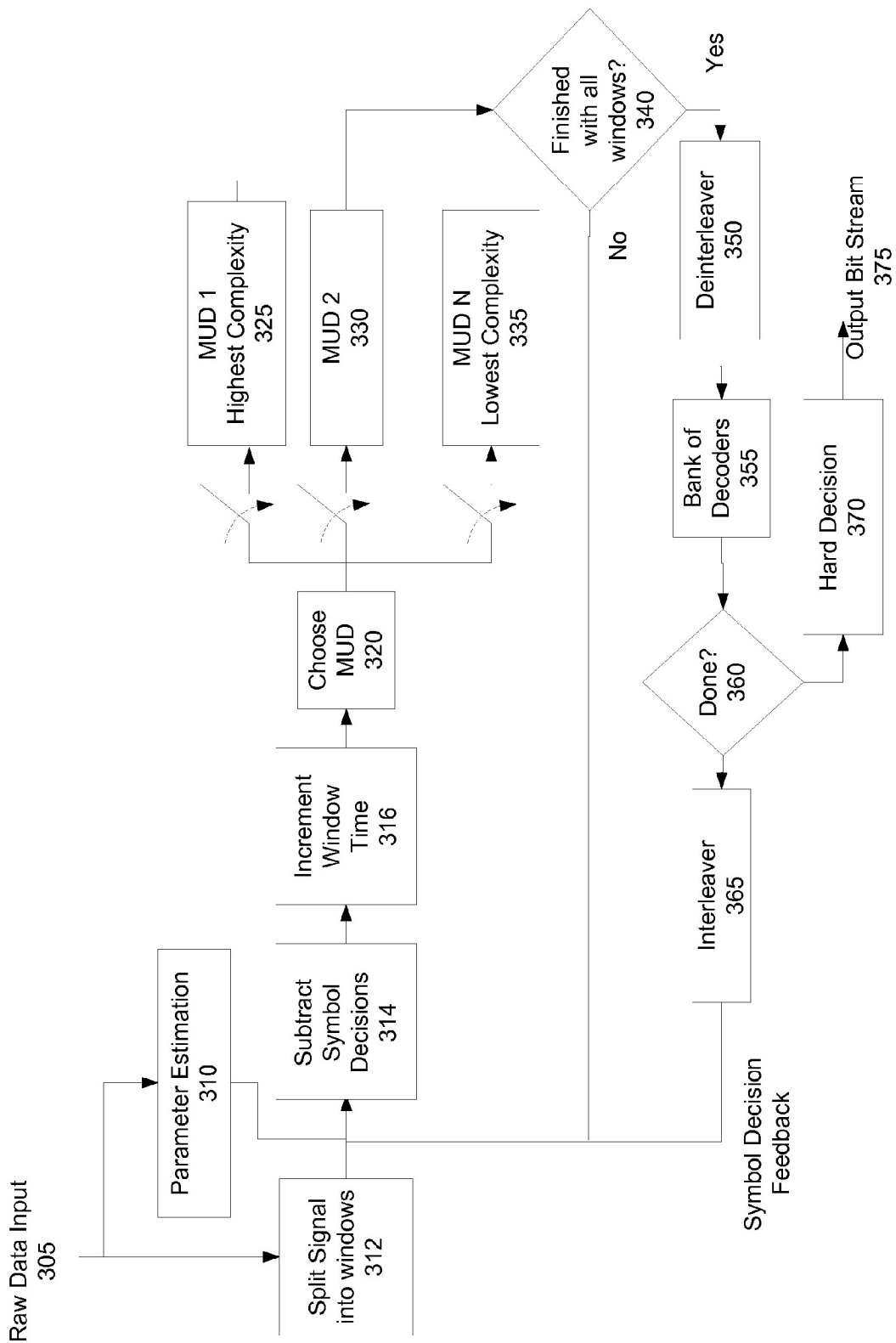


Figure 3

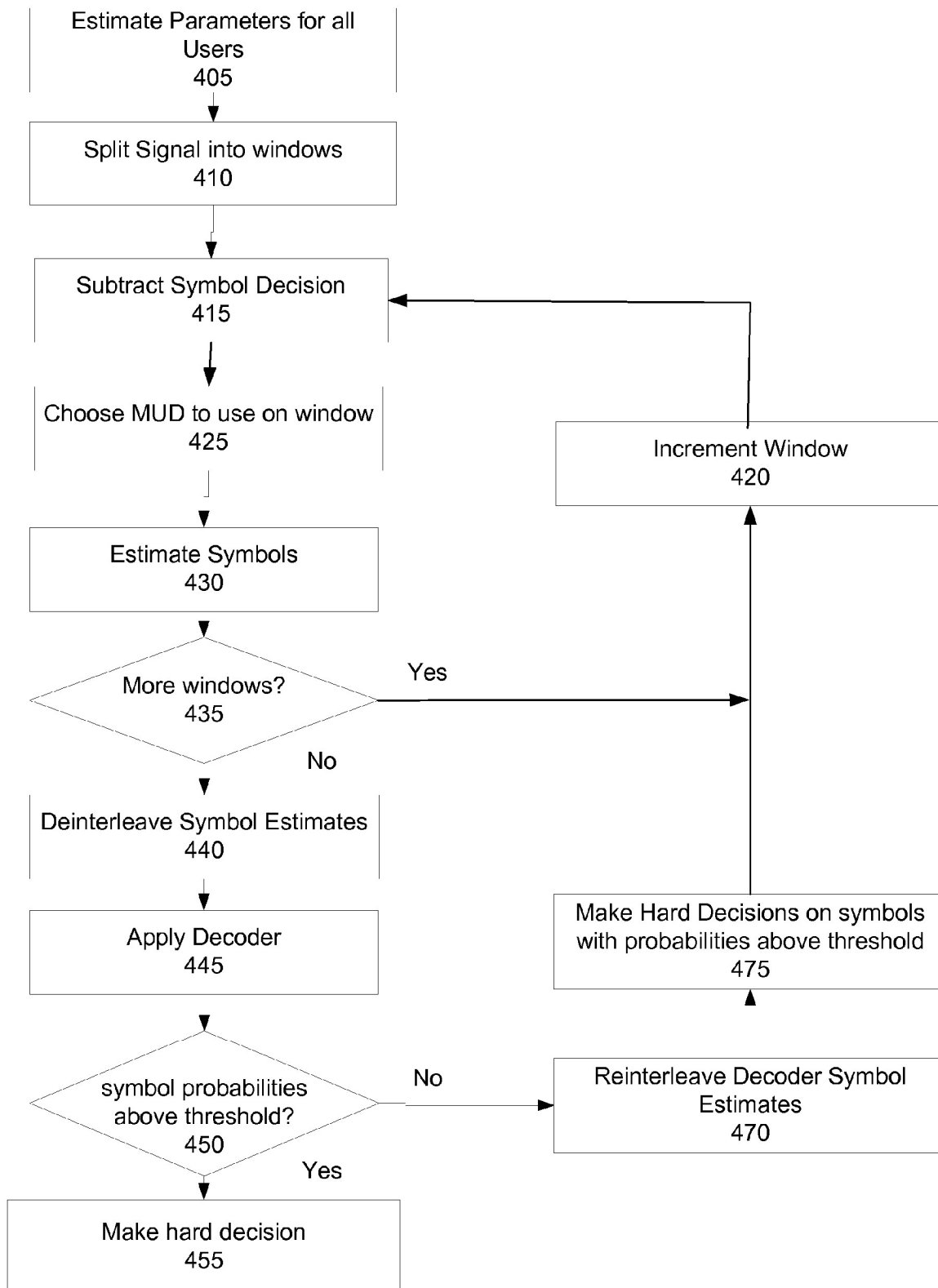
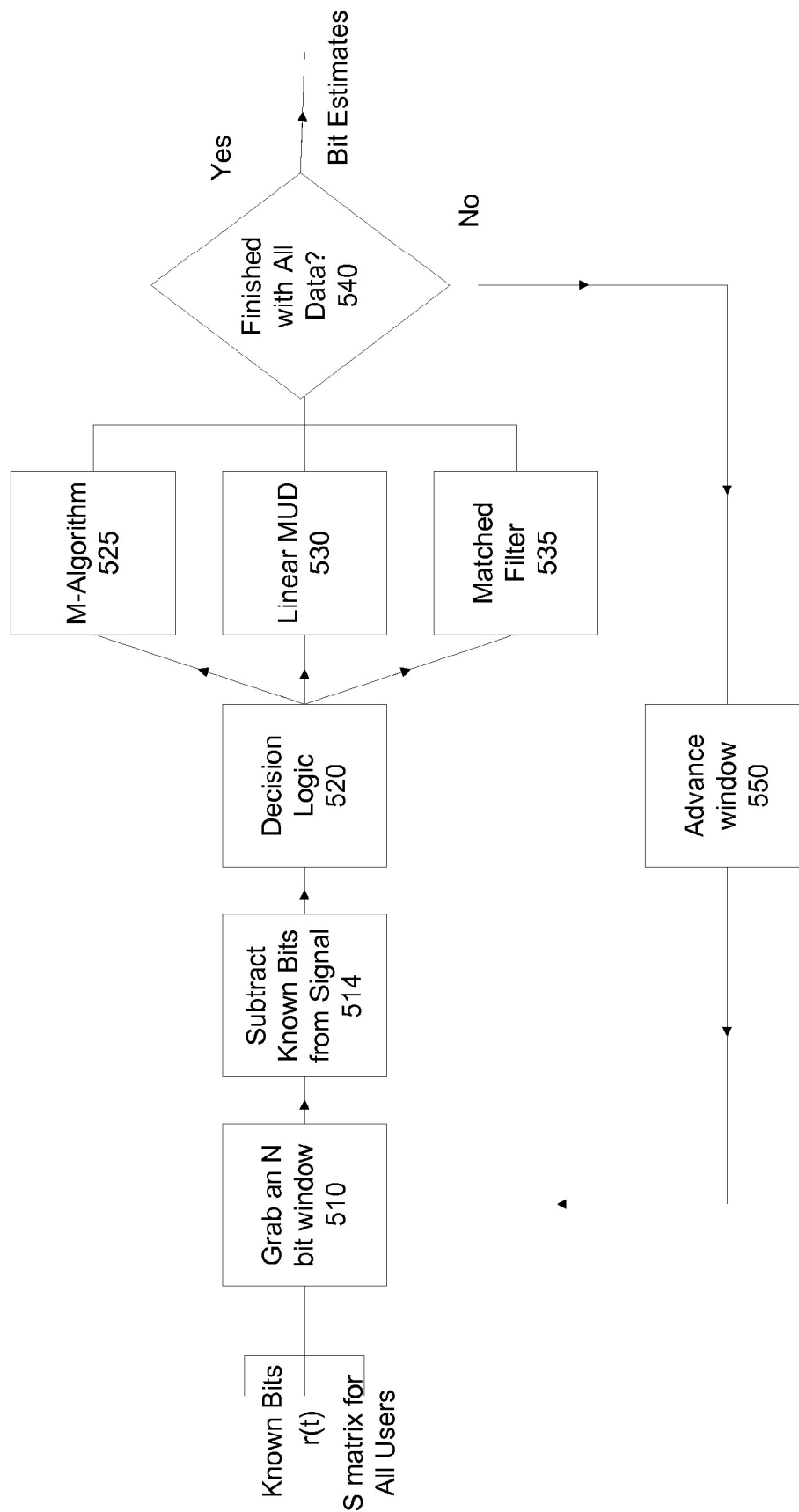


Figure 4



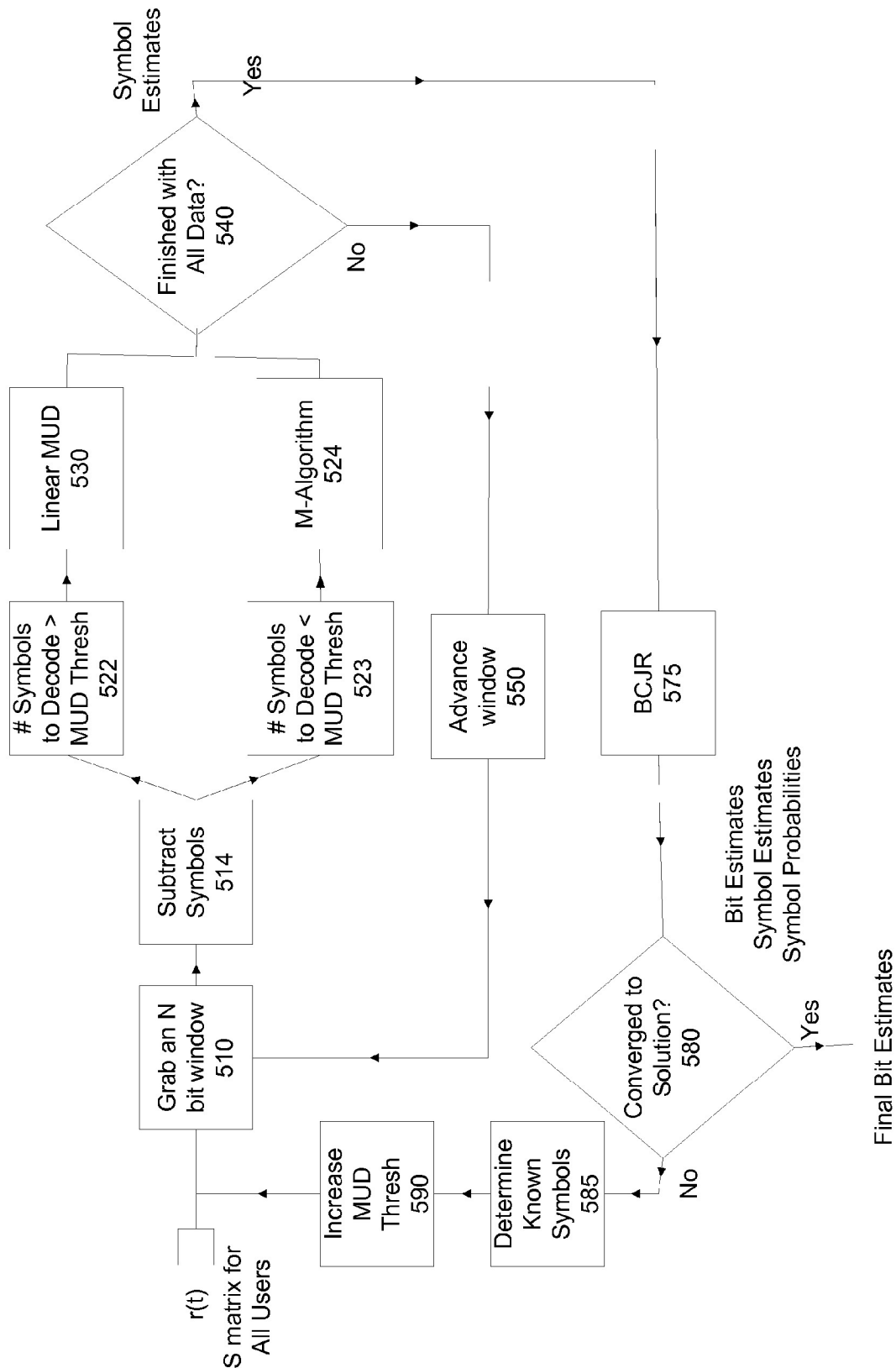


Figure 5b

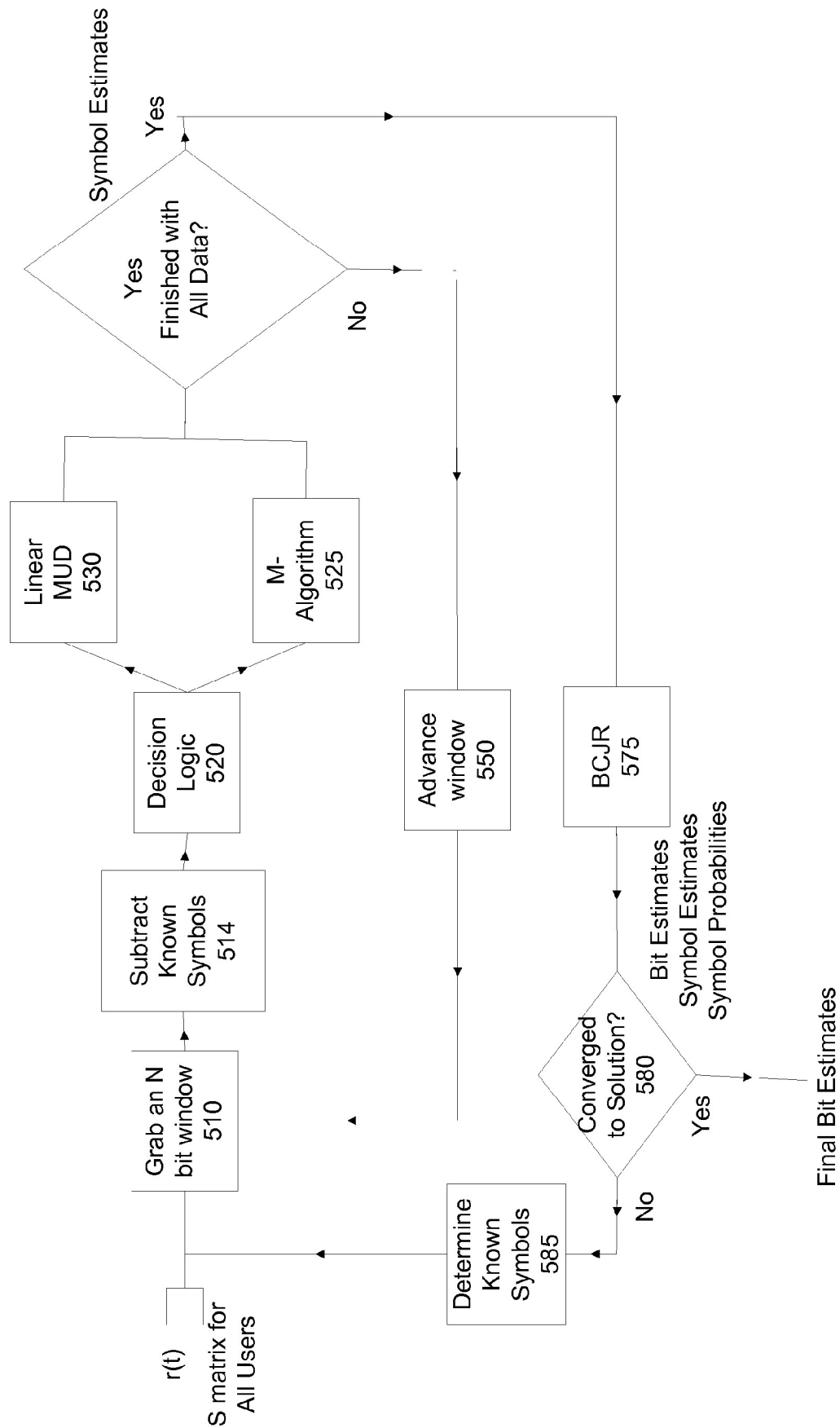


Figure 5c

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COMBINATIONAL HYBRID TURBO-MUD**STATEMENT OF GOVERNMENT INTEREST**

Portions of the present invention have been made in conjunction with Government funding under DARPA Contract No. HR0011-05-C-0064 and there may be certain rights to the Government.

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to U.S. application Ser. No. 10/626,146, filed Jul. 24, 2003, titled "Hybrid Turbo-MUD for Overloaded Multiple Access Systems" which is herein incorporated in its entirety by reference for all purposes.

FIELD OF THE INVENTION

This present invention relates to advanced receiver techniques for processing signals, and more particularly to multi-user detection (MUD) for processing multiple users' signals that interfere with one another.

BACKGROUND OF THE INVENTION

Increased usage and higher content demands have rapidly changed the wireless landscape. The data demands require greater efficiency and the ability to process overloaded environments and extracting more information signals within a limited bandwidth. The multiple-access receiver processing procedures allow for multiple users to access the same communications medium to transmit or receive information. In addition to the problems associated with multiple users in a given bandwidth, an additional problem is the inability to process the data in the receivers in real time. Advanced receiver processing techniques cover several areas, namely interference suppression (also called Multi-User Detection or MUD), multipath combining and space-time processing, equalization, and channel estimation. These various techniques can be mixed and matched depending upon the circumstances. Proper signal processing of transmitter and receiver yield a far greater potential than current systems.

For example, a base station that processes a number of cellular devices has to receive and transmit data within a certain frequency range. The ability to extract the correct data from a given user is a difficult task when the effects of interference and multipaths are considered. The problem is further complicated when the number of users exceeds the number of dimensions (e.g. time slots, frequency slots, polarizations, etc), resulting in an overloaded condition.

In the past, multiple access (MA) communication systems generally utilized Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA) methods to achieve channel access. FDMA refers to the parsing up of an allocated band for a communication system wherein a single user's signal transmission power is concentrated into a single narrower radio frequency band. Interference from adjacent channels is limited by the use of band pass filters for each channel being assigned a different frequency system, total capacity is limited by the available frequency slots and by physical limitations imposed by frequency reuse.

In TDMA systems, a channel consists of a time slot or frame in a periodic train of time intervals over the same frequency, with a given signal's energy confined to one of these time slots. Adjacent channel interference is limited by the use of a time gate or other synchronization element that

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only passes signal energy received at the proper time. The system capacity is limited by the available time slots (within a given frequency band) as well as by physical limitations imposed by frequency reuse, as each channel is assigned a different time slot within a particular frequency band.

One of the goals of FDMA and TDMA systems is to try and prevent two potentially interfering signals from occupying the same frequency at the same time, namely co-channel interference. In contrast, Code Division Multiple Access (CDMA) techniques allow signals to overlap in both time and frequency. CDMA signals share the same frequency spectrum at the same time, hence, the CDMA signals appear to overlap one another. The scrambled signal format of CDMA reduces cross talk between interfering transmitters.

In a CDMA system, each signal is transmitted using spread spectrum techniques. The transmitted informational data stream is impressed upon a much higher rate data stream termed a signature sequence. The bit stream of the signature sequence data is typically binary, and can be generated using a pseudo-noise (PN) process that appears random, but can be replicated by an authorized receiver. The informational data stream and the high bit rate signature sequence stream are combined by multiplying the two bit streams together, assuming the binary values of the two bit streams are represented by +1 or -1. This combination of the higher bit rate signal with the lower bit rate data stream is called spreading the informational data stream signal. Each informational data stream or channel is allocated a unique signature sequence.

In operation, a stream of spread information signature signals are modulated by weights corresponding to the information that is to be transmitted. Some modulation examples include binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK). If several transmitters modulate their data onto the signature waveform and modulate again with the carrier tone, a radio frequency (RF) signal comprised of a continuous stream of information modulated signature pulses will be present at the receiver, one corresponding to each transmitter. The transmitted signals are jointly received as a composite signal at the receiver. Each of the spread signals overlaps all of the other spread signals in time and frequency. Moreover, environmental noise as well as receiver electronic noise is also present in the measured received signal. A conventional CDMA receiver correlates the composite noisy signal with one of the unique signature sequences, and the corresponding information signal is isolated and despread while the other signals appear as only small additions to the noise floor.

A signature sequence is often used to represent one bit of information. Receiving the transmitted sequence or its complement indicates whether the information bit is a +1 or -1, sometimes denoted "0" or "1". The signature sequence usually comprises N pulses, and each pulse is called a "chip". The entire N-chip sequence, or its complement, depending on the information bit to be conveyed, is referred to as a transmitted symbol.

The receiver correlates the received signal with the complex conjugate of the known signature sequence to produce a correlation value. When a 'large' positive correlation results, a "0" is detected, and when a 'large' negative correlation results, a "1" is detected.

It should be understood that the information bits could also be coded bits (also referred to as channel bits or symbols), where the code is a block or convolutional code. Also, the signature sequence can be much longer than a single transmitted symbol, in which case a subsequence of the signature sequence is used to spread the information bit.

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The present systems typically do not properly account for the real world mobile communication signals and the signal degradation such as interference and multipath problems. The system use assumptions that all other interferers and multipaths are additive white Gaussian noise, which is not accurate for co-channel interference and multipaths.

Multipath dispersion occurs when a signal proceeds to the receiver along not one but many paths so that the receiver encounters echoes having different and randomly varying delays and amplitudes. The receiver receives a composite signal of multiple versions of the transmitted symbol that have propagated along different paths, called rays, having different relative time. Each distinguishable ray has a certain relative time of arrival, a certain amplitude and phase, and as a result, the correlator outputs several smaller spikes. RAKE receivers are well known and attempt to 'rake' together all the contributions to detect the transmitted symbol and recover the information bit.

Conventional RAKE receivers provide satisfactory performance for operation in the presence of multipath under ideal conditions however the signature sequence must be uncorrelated with time shifted versions of itself as well as various shifted versions of the signature sequences of the other CDMA signals. Co-channel interference refers to signals received from other users either directly or reflected. If one received signal corresponding to the signature sequence of interest has a non-negligible cross correlation with the received signal originating from another transmitter (a co-channel interferer), then the value measured at the receiver, e.g. the correlation value for the signal of interest, is corrupted. In other words, the correlation computed at the receiver that would be used to decode a particular signal of interest is overwhelmed by an interfering signal; this is referred to as the near-far problem. The interference caused by an echo of one transmitted symbol overlapping with the next transmitted symbol might also be non-negligible. If this is the case, the transmitted symbols interfere with past and future transmitted symbols. This is commonly referred to as intersymbol interference (ISI). In actuality, performance is degraded both by co-channel interference and ISI.

There has been much research to address signal interference with known multipath time dispersion. This is termed joint demodulation with no multipath and is further described in S. Verdu, "Minimum Probability of Error For Asynchronous Gaussian Multiple-Access Channels," IEEE Trans. Info. Theory, Vol. IT-32, pp. 85-96, R. Lupas and S. Verdu, "Linear multiuser detectors for synchronous code-division multiple-access channels," IEEE Trans. Inform. Theory, Vol. 35, pp. 123-136, January 1989; and R. Lupas and S. Verdu, "Near-far resistance of multiuser detectors in asynchronous channels," IEEE Trans. Commun., Vol. 38, pp. 496-508, April 1990.

There are a host of approaches for jointly demodulating any set of interfering digitally modulated signals, including multiple digitally modulated signals. Maximum Likelihood Sequence Estimation determines the most likely set of transmitted information bits for a plurality of digital signals without multipath time dispersion. The maximum likelihood joint demodulator is capable, in theory, of accommodating the largest number of interfering signals, but has a prohibitive computational complexity that makes it unrealizable in practice. The decorrelation receiver is another, less computationally complex receiver processing approach that zeroes out or decorrelates the different signals so that they no longer interfere with one another. The decorrelator as well as virtually every other lower complexity joint demodulator, is not

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capable of operation when the number of signals is over a set threshold which falls significantly short of the theoretical maximum.

In a real world multi-user system, there are a number of independent users simultaneously transmitting signals. These transmissions have the real-time problems of multi-path and co-channel interference, fading, and dispersion that affect the received signals. As described in the prior art, multiple user systems communicate on the same frequency and at the same time by utilizing parameter and channel estimates that are processed by a multi-user detector. The output of the optimal multi-user detector operating within the multiuser capacity limits of the channel is an accurate estimation as to the individual bits for an individual user.

Moreover, in an article by Paul D. Alexander, Mark C. Reed, John A. Asenstorfer and Christian B. Schlager in IEEE Transactions on Communications, vol. 47, number 7, July 1999, entitled "Iterative Multi-User Interference Reduction: Turbo CDMA," a system is described in which multiple users can transmit coded information on the same frequency at the same time, with the multi-user detection system separating the scrambled result into interference-free voice or data streams.

Low complexity multiuser detector have been contemplated that use linear multiuser detectors to achieve optimal near-far resistance. (Near-Far Resistance of Multiuser Detectors for Coherent Multiuser Communications, R. Lupas, S. Verdu, IEEE Trans. Commun. Vol. 38, no. 4, pp 495-508, April 1990). While providing certain advantages, the performance has not been demonstrably improved. Varanasi and Aazhang proposed a multistage technique as described in the article Near-Optimum Detection in Synchronous Code-Division Multiple Access Systems, IEEE Trans. Commun., Vol. 39, No. 5, May 1991.

Decorrelating decision feedback detectors (DDFD) have been described by A. Duel-Hallen in Decorrelating Decision-Feedback Multiuser Detector for Synchronous Code-division Multiple Access Channel, IEEE Trans. Commun., Vol. 41, pp 285-290, February 1993. Wei and Schlegel proposed soft-decision feedback to suppress error propagation of the DDFD in Synchronous DS-SSMA with Improved Decorrelating Decision-Feedback Multiuser Detection, IEEE Trans. Veh. Technol., Vol. 43, pp 767-772, August 1994. Tree-type maximum-likelihood sequence detectors were also proposed for multiuser systems as were breadth-first algorithms and sequential detection including using the M-algorithm tree-search scheme with a whitened matched filter (WMF).

However, one of the primary disadvantages of some of the prior implementations is the inability to accommodate overloaded conditions. The DDFD techniques are limited in that they are incapable of working in supersaturated environments. Generally, only the MMSE-based or tree based decision feedback detector can work in a supersaturated environment, however it is too aggressive with hypothesis testing to produce accurate results.

Multi-user detection (MUD) refers to the detection of data in non-orthogonal channels. MUD processing increases the number of bits available per chip or signaling dimension for systems having interference limited systems. A MUD receiver jointly demodulates co-channel interfering digital signals.

Optimal MUD based on the maximum likelihood sequence estimator operates by comparing the received signal with the entire number of possibilities that could have resulted, one for each bit or symbol epoch. The number of possible measured levels for the received signal is exponentially related to the number of users and the duration of the ISI. Hence, the opti-

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mal processing is a computationally complex and it is not possible to accomplish in a real-time environment. Thus for those multi-user detectors that examine the entire space, real-time operation is often elusive.

In general, optimal MUD units function by examining a number of possibilities for each bit. However, for multi-user detectors that examine a larger capacity of signal, the computations are complex and time-consuming, thus making real-time operation impossible. Numerous attempts at reliable pruning of the optimal MUD decision process or the use of linear approximation to the replace the optimal MUD have still not produced a workable solution for the real world environment.

There are various multiuser detectors in the prior art, including optimal or maximum likelihood MUD, maximum likelihood sequence estimator for multiple interfering users, successive interference cancellation, TurboMUD or iterative MUD, and various linear algebra based multi-user detectors such as all of those detailed in the well-known text "Multiuser Detection" by Sergio Verdu. In basic terms, turbodecoding refers to breaking a large processing process into smaller pieces and performing iterative processing on the smaller pieces until the larger processing is completed. This basic principle was applied to the MUD.

There are several suboptimal multiuser detectors that are less computationally complex and known in the art. One example of suboptimal detectors, called linear detectors, includes decorrelators, minimum mean square error or MMSE detectors, and zero-forcing block linear equalizers. But, certain linear based MUD (non-iterative) and successive interference cancellation fails for cases of overloaded multiple access systems. One example of overloading is where the number of simultaneous users is doubled or tripled relative to existing state of the art. Even for underloaded multiple access systems, the performance of non-iterative MUD and successive interference cancellation degrades significantly as the number of users increases, while the computational complexity of the optimal MUD increases significantly as the number of users increases. The computing problems are so extreme that even the most expensive hardware unbound by size and weight can not keep up with this overwhelming complex processing requirement of optimal MUD. Moreover, an unreasonable delay would be required to decode each bit or symbol rendering such a system useless in practice.

Reduced complexity approaches based on tree-pruning help to some extent to eliminate the improper bit combination from consideration where, ideally, such a procedure should prune out many "bad" paths in the decision tree but maintain the proper path. Thus, the entire tree does not need to be traversed to make the final decision.

The M-algorithm is a pruning process that limits the number of hypotheses extended to each stage to a fixed tree width and prunes based on ranking metrics for all hypotheses and retaining only the M most likely hypotheses. The T-algorithm prunes hypotheses by comparing the metrics representing all active hypotheses to a threshold based on the metric corresponding to the most-likely candidate. Performance of M-algorithm based MUD degrades as the parameter M is decreased, but M governs the number of computations required. Similar effects are seen for other tree-pruning based MUD (T-algorithm, etc). To combat improper pruning, basic tree-pruning must ensure that M is "large enough", and therefore still encounters increased complexity for acceptable performance levels when the number of interfering signals and/or ISI lengths are moderate to large.

As an illustration of the M-algorithm as a tree-pruning algorithm, consider a tree made up of nodes and branches.

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Each branch has a weight or metric, and a complete path is sequences of nodes connected by branches between the root of the tree and its branches. When applied as a short cut to the optimal MUD, each branch weight is a function of the signal value associated with that transmitter at that point in time, and the actual received signal which includes all the signals from all the interfering transmissions. The weight of each path is the sum of the branch metrics in a complete path. The goal of a tree searching algorithm is to try to find the complete path through a tree with the lowest metric. With the present invention the metrics of multiple complete paths are not calculated. Rather, the metrics of individual branches in a tree are calculated in the process of locating one complete path through the tree and thereby defines one unknown characteristic of each of the co-channel, interfering signals needed to decode the signals.

A MUD algorithm within the TurboMUD system determines discrete estimates of the transmitted channel symbols, with the estimates then provided to a bank of single-user decoders (one decoder for each user) to recover the input bit streams of all transmitted signals. Two general types of multi-user detectors within the TurboMUD system are possible, namely those that provide hard outputs, which are discrete values, and those that provide soft outputs, which indicate both the discrete estimate and the probability that the estimate is correct.

However, single-user decoders operating on hard values, or discrete integers, have unacceptable error rates when there is a large amount of interference or noise in the received signal. The reason is that discrete integers do not provide adequate confidence values on which the single-user decoder can operate. These decoders operate better on so-called soft inputs in which confidence values can range from -1 to 1, such as for instance 0.75 as opposed to being either -1 or +1. To provide soft values that can then be utilized by a single-user decoder, the multi-user detector chosen for the TurboMUD can generate these soft values. The invention described below will work with soft output or a hard output MUDs, or a combination of the two.

In general, soft or hard output versions of the optimum maximum likelihood multi-user detector (Verdu, Multiuser Detection, Cambridge University Press, 1998) or an M algorithm (as described, for instance, in Schlegel, Trellis Coding, IEEE Press, 1997) with a moderate to high value of M causes the Turbo MUD to require too many computations to keep up with real time transmissions. Using a fast, but inferior, multiuser detection scheme such as a linear-based detector or those detailed in the text "Multiuser Detection" by Sergio Verdu causes poor quality output when there are many or strongly correlated interferers or users.

Moreover, when dealing with hand-held communications units such as wireless handsets, the amount of processing within the device is limited, directly limiting the amount of computational complexity that is allowed. In order to provide real-time performance both at a cell site and the handset, it therefore becomes important to be able to reduce the amount of computational complexity and processing time so as to achieve real-time performance.

The growing demand for processing more data and in a smaller bandwidth raises the need to optimize performance. What is needed is an efficient signal processing system and processing to improve the quality and spectral efficiency of

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wireless communications and better techniques for sharing the limited bandwidth among different high capacity users

SUMMARY OF THE INVENTION

The invention is devised in the light of the problems of the prior references described herein, and a general object is to provide a more efficient MUD processing that still provides a satisfactory bit error rate (BER).

One embodiment of the invention is a hybrid Multi-User Detector System for processing received signals, having a parameter estimator coupled to the received signals providing received data information. There is a multi-user detector decision unit coupled to the parameter estimator and the received signals with at least two multi-user detectors coupled to the parameter estimator and the multi-user detector decision unit. The multi-user detector decision unit uses decision criteria to determine a selected multi-user detector, and the selected multi-user detector outputs a plurality of information streams, one stream corresponding to each of the received signals. There are a bank of decoders, such as low complexity decoders and high complexity decoders, coupled to the plurality of information streams, wherein the decoders output a plurality of improved information streams.

In a turboMUD embodiment, the plurality of improved information streams are fed back to the multi-user detector decision unit until a final condition is reached and the bank of decoders output a final data stream.

According to one embodiment, the design criteria is based upon at least one threshold, where the threshold is selected from at least one of the group consisting of: number of symbols, correlation matrix between users, expected bit error rate, eigendecomposition of correlation matrix, signal to interference plus noise ratio, and expected SINR. In addition, the threshold can be dynamically changeable such that at each iteration the threshold can be changed. The threshold can also be changed depending upon which multi-user is selected. There can also be multiple thresholds for the various multi-user detectors.

An additional embodiment includes wherein the at least two multiuser detectors are selected from the group consisting of: M-algorithm, T-algorithm, FANO, reduced state Viterbi, Maximum Likelihood, matched filter, mean squared error (MMSE), decorrelator, and combinations thereof.

A further feature includes an interleaver unit and a deinterleaver unit coupled between the bank of decoders and the multi-user detectors. There can also be a filter unit coupled to the received signals, wherein the filter unit is coupled to the multi-user detector decision unit. In addition, there can be a hard decision unit coupled to the bank of decoders and producing the final data stream. In one variation the final condition is determined by one of a fixed number of iterations and an allowable performance level.

One embodiment of the invention is a hybrid receiver for processing a plurality of received signals, the receiver comprising a parameter estimation unit coupled to the received signals, wherein the parameter estimation unit extracts received signal information. There is a multi-user detector decision unit coupled to the parameter estimator and the received signals. A low complexity multi-user detector is switchably coupled by the multi-user detector decision unit, wherein the low complexity multi-user detector outputs a plurality of low complexity processed information streams. A high complexity multi-user detector is switchably coupled by the multi-user detector decision unit, wherein the high complexity multi-user detector outputs a plurality of high complexity processed information streams. A bank of decoders is

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coupled to the plurality of low complexity processed information streams and the plurality of high complexity processed information streams, wherein the decoders output a plurality of refined information streams. In one embodiment the receiver uses the high complexity multi-user detector after first processing with the low complexity multi-user detector.

A turboMUD embodiment wherein said plurality of refined information streams are fed back to said multi-user detector decision unit for iterative processing until a final condition is reached and the bank of error correction decoders output a final plurality of symbol streams.

In one embodiment the multi-user detector decision unit makes a selection determined by design criteria based upon at least one threshold selected from at least one of the group consisting of: number of symbols, correlation matrix between users, expected bit error rate, eigendecomposition of correlation matrix, signal to interference plus noise ratio, and expected SINR.

One variation includes the hybrid receiver having a front end section coupled to the received signals and to the received signal information which filters the received signals.

A further embodiment of the invention is a method for processing signals from multiple users providing raw digitized data. The method include performing parameter estimation of the raw digitized data, grabbing a window of bits from the raw digitized data, subtracting any known bits from the window of bits, selecting a multi-user detector, computing decision tree searching path metrics from the window of bits using the multi-user detector, incrementing to a next window of bits, repeating the steps of subtracting, selecting, computing and incrementing until there are no more windows, and outputting a set of symbol estimates.

As detailed herein, the multi-user detector is selectable from the group consisting of high complexity multi-user detectors, low complexity multi-user detectors and matched filters.

One method for determining a size of the window is by using an intersymbol interference length and a cochannel interference length.

According to one embodiment the method includes checking the symbol estimates for a threshold condition. The method includes outputting a final symbol stream for each user if passing the threshold condition, and repeating the steps of subtracting, selecting, computing and incrementing if failing the threshold condition.

The features and advantages described herein are not all-inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and not to limit the scope of the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

FIG. 1 shows a block diagrammatic presentation of a prior art conventional turbo MUD system illustrating the iterative processing that takes advantage of improvements in partial information gained with each iteration through the use of conditional probabilities for each decoded symbol of each user.

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FIG. 2 is a block diagrammatic perspective according to one embodiment of a hybrid MUD that selects the MUD based on certain metrics;

FIG. 3 is a block diagrammatic perspective of a hybrid MUD in accordance with one embodiment of the present invention;

FIG. 4 is a flow chart showing processing steps according to one embodiment;

FIG. 5a illustrates a block diagram system of the present invention in accordance with one embodiment;

FIG. 5b illustrates a block diagram system of the present invention in accordance with another embodiment; and

FIG. 5c illustrates a block diagram system of the present invention in accordance with a further embodiment.

DETAILED DESCRIPTION

The methods and embodiments of the Hybrid Turbo-MUD disclosed herein enable implementations of advanced receiver processing providing high quality real-time processing for multiple access systems, including overloaded conditions. The embodiments herein illustrate digital processing technique applicable to many variations and applications all within the scope of the invention.

Referring to FIG. 1, the basic iterative MUD procedure is diagrammatically presented, and is well known from published literature such as Poor, "Turbo Multiuser Detection: An overview," IEEE 6th Int. Symp. On Spread-Spectrum Tech. And Appl., NJIT, New Jersey, Sep. 6-8, 2000 and Alexander, Reed, Asenstorfer, and Schlegel, "Iterative Multiuser Interference Reduction Turbo CDMA," IEEE Trans. On Comms., v41, n7, July 1999. The iterative MUD is representative of the approaches used to incorporate turbo decoding methods into joint MUD/FEC (Forward Error Correction) decoding and to then reduce the complexity of the system.

It should be readily appreciated that there are two general embodiments applicable to the MUD of FIG. 1, namely an iterative embodiment and a non-iterative embodiment. The iterative embodiment or Turbo-MUD is described herein while the non iterative MUD merely runs a single cycle through the process.

The raw input data represents data after some front end processing such as downconversion, amplification, and analog-to-digital conversion, although other forms of communication have been contemplated herein. The input signal of raw non-manipulated data at the receiver is comprised of the aggregate of many signals from many different transmitters, where each signal is assigned a signature pulse for the transmission of symbols. Traditionally, these signature pulses occupy either a specific frequency, timeslot, and/or spreading code and are referred to as occupying a specific channel from a finite set of channels. In a typical scenario, the aggregate signal is collected at the receiver, down-converted and digitized.

A parameter estimation unit 10 processes the various parameters for the received raw data, and provides certain information to the MUD 20. The purpose of the parameter estimator 10, is to provide the receiver information such as estimate timing offsets, signal amplitudes, carrier phases, polarizations, channel transfer functions, carrier frequency offset or Doppler frequency offset, coding rates, identification of active channels, as well as any other information required by the MUD to carry out its processing. The parameter estimation unit is known in the art, and a detailed description is available in U.S. Pat. No. 6,947,505 entitled "System

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for Parameter Estimation and Tracking of Interfering Digitally Modulated Signals", which is incorporated by reference herein.

This digital input signal or raw input data is then input to the multiuser detector (MUD) 20. The MUD processing can employ the various state of the art schemes, including M-algorithm, T-algorithm, Fano-algorithm and other tree-pruned approaches known to those in the art. The MUD processing can also employ a lower complexity linear MUD with a higher expected BER. MUD systems generally require some user signal parameters in order to establish accurate decision trees for processing.

In an optimal case, the MUD detector 20 can be a full-complexity maximum a posteriori (MAP) detector. Suboptimal reduced complexity MAP-based approaches are also known in the relevant art. The data streams from the MUD 20 are passed to a bank of error correction decoders unit 40. In the non-iterative MUD, the raw data is processed by a MUD algorithm which outputs an estimate of each transmitted symbol corresponding to each active user/channel. These stream of symbols, likely corrupted by errors, are passed to the bank of error correction decoders unit 40, one for each user/channel, which is capable of outputting either a corrected symbol stream for each user (hard decision decoder) or a real number corresponding to the likelihood that each symbol is some specific value (soft decision decoder). For convenience, the terms channel bits, coded bits, and symbol are deemed equivalent and may be used interchangeably.

The MUD engine 20 within the TurboMUD can be structured for hard or soft output as well as hard or soft input processing, however in order to demonstrate a working embodiment, the soft input and soft output version is addressed herein, but it is well within the scope of the present invention to utilize any combinations of the other options.

In a Turbo-MUD system, decoding and confidence information is passed between the MUD 20 and decoder components 40. Maximum a posteriori (MAP) decoders (or approximations of MAP decoders) are well known to those in the art and are used for both the MUD and single-user (SU) decoders, so that soft output information is available if desired. The MUD 20 assumes knowledge of various parameters such as relative received timing offsets, carrier phase, frequency offsets, received amplitudes, and multipath structure for each of the interfering signals present in the received signal.

The multiuser detection unit 20 outputs a bit (or symbol) stream associated with each interfering signal present on the channel for one data block. Deinterleavers and interleavers (not shown) are optional elements coupled between the MUD 20 and the decoders 40 that are used if the transmitted signals are interleaved, such as the CDMA format. The MUD detector 20 passes soft decisions in the form of reliability, or confidence, measures to the decoders 40. The reliability measures are presented with one associated with each symbol of each user to the bank of decoders 40. If the signals were transmitted with interleaving, the reliability measures from the MUD 20 are first passed through a deinterleaver (not shown) and passed on in shuffled form to the decoder 40. Shuffling refers to processing the same values but changes the placement or presentation of the values. If interleaving was present in the transmitter, an interleaver unit performs interleaving. The time-shuffled conditional probabilities are input back to the MUD section 20. When the transmitter employs interleaving it changes the presentation of the values but not the values themselves. For example, IS-95 is the North American Cell Phone standard that employs interleaving.

In one known variation, there is a bank of error correction decoders 40 that provide soft output or restore values associ-

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ated with prior probabilities. Viterbi decoders can be used, but generally outputs hard values. The single user decoders calculate conditional probabilities, one for each decoded symbol of each user, and output them as confidence values back to the MUD 20. Soft input soft output decoders, such as MAP or soft-output Viterbi algorithm (SOVA) decoders are examples known in the art. As the output of the decoders 40 is taken here for discussion purposes to be soft values, it should be understood that the hard decision is optional depending upon the application and the implementation requirements.

MAP decoding is known in the art and further described in C. Schlegel, Trellis Coding, IEEE Press, 1997; Robertson, Villebrun and Hoeher, "A Comparison of Optimal and Sub-Optimal MAP Decoding Algorithms Operation in the Log Domain," ICC95; Hagenauer, and Hoeher, "A Viterbi Algorithm with Soft-Decision Outputs and its Applications," Globecom 89; Pottie and Taylor, "A Comparison of Reduced complexity Decoding Algorithms for Trellis Codes," J Sel. Areas in Comm December 1989. The iterative turbo principle, on which Turbo MUD is based, is described by Berrou, Glavieux, and Thitimajshima, "Near Shannon Limit Error-Correcting Coding and Decoding: Turbo-Codes (1)," ICC 93; Berrou and Glavieux, "Near Optimum Error Correcting Coding and Decoding: Turbo-Codes", Trans on Comm, October 1996; and Wang and Kobayashi, "Low-Complexity MAP Decoding for Turbo Codes", Vehicular Technology Conference 2000]. Turbo MUD approaches are described in, for example, Alexander, Reed, Asenstorfer, and Schlegel, "Iterative Multiuser Interference Reduction Turbo CDMA," Trans on Comm, July 1999; Poor, "Turbo Multiuser Detection: An Overview," ISSSTA 2000; and Wang and Poor, "Iterative (Turbo) Soft Interference Cancellation and Decoding for Coded CDMA", Trans on Comm, July 1999.

For TurboMUD, soft outputs for each bit of each user from the bank of decoders 40 are fed back to the MUD 20 for each iteration. The multiuser detector 20 takes these soft inputs along with the original raw input signal to calculate an improved, less corrupted bit stream for each user. This iterative process continues until the desired quality is reached or a fixed number is reached 30. At that point, estimates of the data sequences for all active users are output. Operation then commences for the next block of data, repeating the process described above.

The number of iterations for processing between the MUD 20 and the decoders 40 can be set to a fixed counter or by checking if there were significant changes to the data from the last iteration. Once the data is no longer being altered or reaches a certain iteration counter limit, the data from the decoder 40 can be output as final estimates of what the user sent. A fixed number of iterations can be stored as the stopping point and used and processed by the decision block 30. Alternatively, the information between the MUD 20 and the decoders 40 repeats in subsequent iterations until an asymptote is reached or the desired performance level is attained. A buffer can store the previous values and compare them to the latter processed values during the iterative process.

When processing is completed 30, the soft output of the bank of error decoders 40 is passed to a hard decision unit 50 which outputs the final stream of decisions or output data stream for each interfering user for the current data block. The process is repeated for all subsequent data blocks. As described herein, this prior art TurboMUD suffers from limitations with respect to real-time processing of data in a multi-user environment due to the complexity of the MUD processing. The optimal MUD (an exhaustive search of all possible received signals given the set of known parameters and known signature pulses) must check an inordinate number of

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possibilities. A good alternative to the exhaustive search in the pruned tree search such as the M-algorithm, T-algorithm, or Fano sequential decoder. The problem with these, however, is that when the number of interfering users is very large, as is often the case in an overloaded environment, the computational complexity required to achieve any reasonably good bit error rate does not allow for real time operation. In other words, the time it would take to do the processing with computing resources does not allow the decoded symbols to be output at the bit rate the user's are transmitting. This causes the processor to fall farther and farther behind the transmitted information streams. There is another option for a truly low complexity MUD, however, there are associated problems with using a truly low complexity suboptimal MUD for the MUD engine. Specifically, a low complexity MUD such as a minimum mean squared error (MMSE) MUD does a very poor job decoding all the user's symbols when the interference levels or the correlations between the users are very high, as is the case in an overloaded system.

As described, there are several types of MUD that have been developed to solve the overloaded user communications scenario. While the maximum likelihood (ML) detector is optimal if the coding in the signals is not used and each user is detected symbol by symbol, running an exhaustive ML search is not computationally practical or feasible. Linear MUD detectors have been developed to setup linear decision regions which, unlike the matched filter, take all the interfering users into account when setting up the decision regions. Two examples are the decorrelator detector and the MMSE detector.

$$\text{Decorrelator: } \hat{b} = (S^H S)^{-1} y$$

$$\text{MMSE: } \hat{b} = \left(S^H S + \frac{\sigma^2}{A^2} \right)^{-1} y$$

where y is equal to the matched filter outputs.

$$y = S^H S A b + n$$

These detectors are computationally simple but their performance suffers when the loading is high or when the correlation structure of the users is unfavorable.

Fortunately, low complexity detectors can still detect some of the users in an overloaded environment. Users who have favorable correlation structures, or higher powers will often times be detected using a lower complexity linear MUD. This allows the user to optimize the MUD performance by implementing a hybrid MUD structure as described herein in the turbo MUD.

Referring to FIG. 2, which shows one embodiment the present invention which incorporates a decision block to choose the MUD based on some metric. In basic terms, the hybrid MUD system of the present invention optimizes the MUD algorithms for a balance between computational complexity and performance. The turbo MUD performs successive interference cancellation in an iterative loop by combining a detector with a decoder that feeds back symbol estimates as well as probability of error estimates for each symbol. There are some MUD systems that employ a fixed approach to the turbo MUD processing such as having a high complexity MUD on the first iteration and then lower complexity MUD processing for subsequent iterations. However, the present invention provides for selecting the MUD at each iteration, or selecting the MUD within each bit window, based on certain criteria.

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A brief description according to one embodiment is as follows. The raw data input **205** is fed to the parameter estimator **210** and also to a MUD decision unit **220**. The MUD algorithms **225, 230, 235** within the turbo MUD can be structured for hard or soft output as well as hard or soft input processing, and it is well within the scope of the present invention to utilize any combinations thereof.

The raw data is processed by the MUD algorithm and outputs a soft or hard output. The soft output is an estimate of each transmitted symbol corresponding to each active user/channel. The stream of symbols, likely corrupted by errors, are passed to the bank of error correction decoders **255**, one for each user/channel, which is capable of outputting either a corrected symbol stream for each user or a real number corresponding to the likelihood that each symbol is some specific value.

The MUD **225, 230, 235** assumes knowledge of various parameters such as relative received timing offsets, carrier phase, frequency offsets, received amplitudes, and channel structure for each of the interfering signals present in the received signal. The chosen MUD **225, 230, 235** outputs, for each user, a bit (or symbol) stream or a stream of soft values corresponding to the probability that a certain bit or symbol was sent by each user. The chosen MUD **225, 230, 235** is typically coupled to the parameter estimation unit **210** for obtaining information on the received signals, especially for the highest complexity MUD **225**. An optional deinterleaver **250** is employed for transmission received in an interleaved format, such as CDMA. These symbol streams are sent to a bank of error correcting decoders **255**, which can be optionally interleaved **265** before being passed back to the MUD decision unit **220** that selects the next MUD **225, 230, 235**.

As indicated, the MUD decision unit **220** that selects from among at least one MUD **225, 230, 235** represents one of the inventive aspects of the present invention. There are many different ways that the decision can be made. The following list and descriptions are examples of possible decision metrics and are not to be considered an inclusive list or limitation to the invention. A simple way to make the decision on which MUD to use is based on the number of symbols that are being detected in a specific MUD window. A threshold can be set for every MUD technique and when the number of symbols falls below a given MUD technique's threshold it is used for demodulation. As turbo iterations progress the thresholds can change in order to allow remaining symbols that have not been removed in the Turbo iteration to go towards more complex MUD techniques. The reason for this is that the initial low complexity MUD techniques will be able to process a certain amount of symbols, while the symbols that the low complexity MUD cannot demodulate correctly will be sent to higher complexity MUDs as the process continues. However, for this further processing the overall number of symbols has been reduced by the low complexity MUD so the complexity of the higher complexity MUD is reduced as well.

Another technique for making the decision is to look at the correlation matrix between the users and comparing each diagonal term to the sum of the off diagonal correlation terms. If the ratio for a certain number of users is greater than a certain threshold then a lower complexity MUD can be used. If the ratio is below that threshold then a higher complexity MUD can be used. If more than two types of MUD are used, then multiple thresholds can be set for each MUD.

The decision can be made by calculating the expected bit error rate (BER) of each user based on all the lower complexity MUD techniques. If any of the users have an expected BER that is acceptable, or above a threshold, for any of the lower complexity MUD techniques, then use the lowest com-

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plexity MUD possible that meets that criteria. As users are removed through the turbo iteration the expected BER of the remaining users changes. If none of the users in a specific window have an expected BER below the threshold for any of the lower complexity MUD techniques then the highest complexity MUD technique should be used.

The decision can be made by taking the eigendecomposition of the correlation matrix and looking at all the eigenvalues that are above the noise floor. If the first N eigenvalues are very close to one another and the eigenvectors associated with those eigenvalues all have the same N entries terms then use a lower complexity MUD. If there are any other regions of the eigenvalues that are basically equal and the eigenvalues have the same dominant terms or if there is any one eigenvector that has a dominant term and its eigenvector is above the noise floor then use a lower complexity MUD. If the eigenvalues and eigenvectors of the correlation matrix do not have these characteristics then use the highest complexity MUD.

The decision can be made by calculating the signal to interference plus noise ratio (SINR) for each symbol. If the SINR for any symbols is above a threshold set for a specific lower complexity MUD technique then use that technique. If none of the SINR values are above any of the lower complexity MUD thresholds then use the highest complexity MUD.

The decision can be made by calculating the expected SINR value for each symbol after filtering with one of the lower complexity MUDs. If the SINR is above a threshold set for a specific lower complexity MUD technique then use that technique. If none of the post filtering SINR values are above any of the lower complexity MUD thresholds then use the highest complexity MUD.

Inside the turbo loop, a decision is made by the MUD decision unit **220** as to which MUD decoder to use based on certain criteria. The criteria can include such aspects as computational complexity, the number of bits to detect, expected BER of each detector for all users, and correlation structure. There can be a plurality of MUD units available for selection. The MUD decision unit **220** in this example decides between lower complexity linear mud **235**, a medium complexity MUD **230** and a high complexity MUD **225**.

In a turbo MUD system, decoding and confidence information is passed between the selected MUD **225, 230, 235** and decoder **255**. Maximum a posteriori (MAP) decoders (or approximations of MAP decoders) can be used for both the MUD and single-user (SU) decoders, so that soft output information is available if desired.

According to one embodiment, the system achieves optimal balance by using the low complexity algorithm **235** when there are a lot of bits to decode or there are certain users which have a low probability of error with the linear detector, and by using a high complexity algorithm **225** when there are very few users to detect, or the correlation structure of the remaining users implies that a linear MUD will not be able to successfully correctly detect any of the users at a required BER.

The MUD decision unit **220** according to one embodiment detects as many users as possible with a low complexity MUD **235** such as the algorithm. The low complexity MUD **235** provides symbol estimates and probabilities of error for each symbol and decisions which are then subtracted off the signal. As the MUD progresses through the turbo loops, it reaches a point where the correlation structure of the remaining users are closer and the low complexity MUD **235** will no longer be able to satisfactorily detect the users in certain windows. At this point, the computational complexity has been reduced by the low complexity MUD **235** by stripping bits off of the received sequence. This allows the higher complexity MUD

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225 such as the ML detector or M-algorithm to perform much more efficiently on the remaining symbols.

For example, decision logic may be based on BER calculations for each of the MUDs, the correlation structure, and number of bits to decode. By way of example, the number of bits remaining to decode may be used as the decision metric. In this implementation a threshold is set and compared to the number of bits to detect in each bit window. This number varies from window to window because changing correlation structures mean that a different amount of bits might be subtracted off the sequence for each window. Also users could be turning on or off during the sequence which would change the amount of bits per window in the initial turbo iteration. If the number of bits is above the threshold, a low complexity MUD 235 is used, if the number of bits is below the threshold a higher complexity MUD 225 is used. If the number of users left to decode is equal to 1 then a very low complexity detector such as a matched filter can be used (assuming no intersymbol-interference). For each iteration through the turbo MUD, the threshold can be increased so that more users can go to the high complexity MUD 225 in the later iterations.

Referring again to FIG. 2, in one embodiment, decoders 255 provides a soft outputs in the form of a stream of values corresponding to the probability that a certain bit or symbol was transmitted within each interfering user's signal present in the received signal. The soft data streams are passed to the chosen MUD 225, 230, 235 and the soft bit (or symbol) decisions are passed the optional deinterleaver 250 and then to a bank of error correction decoders 235. The interleaver 265 and de-interleaver 250 are used with interleaved transmissions, such as CDMA. Decoders 235 outputs soft values associated with the soft inputs, one stream of outputs for each interfering user present in the received signal. If not done 260, the time-shuffled conditional probabilities are input back to the decision unit 220 for iterative processing.

These soft outputs are passed back to the MUD decision unit 220 that selects the MUD 225, 230, 235 based upon the metrics for the remaining symbol decisions in the window. The MUD processing continues with the chosen MUD 225, 230, 235 and deinterleaved by the optional deinterleaver 250 that produces an improved stream of soft bit (or symbol) decisions that are then fed into the decoder 255 for another iteration of improvement. The information between the chosen MUD 225, 230, 235 and the decoders 255 repeats in subsequent iterations until an asymptote is reached, or the desired performance level is attained.

The number of iterations for processing in the turbo MUD loop can be set to a fixed counter or by checking if there were significant changes to the data from the last iteration. For example, once the data is no longer being altered or reaches a certain iteration counter limit, the data from the decoder 255 can be output as final estimates 270 of what the user sent.

When the desired quality of detection is reached (or a fixed number of iterations), and the processing is done 260, the soft output of decoder 255 is passed to the hard decision unit 270 for processing the hard decisions. The final stream of bits or symbols is output 275, one stream for each user present in the interfering signal. Operation can then commence for the next block of data, repeating the process described herein.

Interleaver 265 and de-interleaver 250 are optional elements used when interleaving is present in the transmitted communications. When the transmitter employs interleaving it changes the presentation of the values but not the values themselves. When interleaving is present in the transmitter, a transmitter interleaver unit (not shown) performs interleaving, and therefore requires the deinterleaver units 250 and interleaver units 265 on the reception end. Thus, in one

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embodiment, the system provides hard decisions with the MUD 225, 230, 235 and bank of decoders 255 for a reduced multi-access interference multiuser detector and hard decision error correction decoder.

According to one embodiment of the invention, the first iteration through the MUD is performed using the lower complexity MUD 235 such as a simple matched filter. Match filters are typically used if there are very few users, but even in situations with multiple users, the match filter can strip off some users. The complexity of the MUD processing depends upon the number of users, thus stripping off even a few users by using the low complexity MUD will allow the higher complexity MUD to be faster and more efficient. Thus, higher complexity MUD 225 can be used for the highly correlated signals that require the higher complexity processing.

The higher complexity MUD 225 can use better performing algorithms such as M-algorithm, T-algorithm, FANO or reduced state Viterbi. Iterations of the Turbo-MUD with the lower complexity MUD algorithms allow the present invention to operate in real-time and with lower complexity computational processing.

In one embodiment, the low complexity MUD 235 is any low complexity soft decision input soft decision output multiuser detector known in the art. Furthermore, the turbo MUD section comprising the low-complexity MUD 235, optional deinterleaver 250, bank of decoders 255, optional interleaver 265, decision block 260, and hard decision block 270 could be replaced with the low-complexity iterative MUD such as described in the incorporated patent applications, or the linear-based soft decision MUD known in the art and described in Chan and Wornell, 'A Class of Asymptotically Optimum Iterated-Decision Multiuser Detectors', or Wang and Poor, 'Iterative (Turbo) Soft Interference Cancellation and Decoding for Coded CDMA', IEEE Trans. on Comms, July 1999, or Moher, "An iterative multiuser decoder for near capacity communication," IEEE Trans. on Comms., v46, n7, July 1998.

For illustrative purposes, MUD can be considered as a tree pruning algorithm, wherein the tree is made up of nodes and branches. Each branch has a weight or metric, and a complete path is a sequence of nodes connected by branches between the root of the tree and its branches. The weight of each path is the sum of the branch metrics in a complete path. The goal of a tree searching algorithm is to try to find the complete path through a tree with the lowest metric.

It should be apparent to those skilled in the art that any tree pruned search such as Fano algorithm, M-algorithm, T-algorithm or reduced state Viterbi can be used as the MUD decoders in the Turbo-MUD processing. The illustration and description of the M-algorithm is not a limitation to the invention and is merely one way to do a sub-optimal search that prunes some decisions without doing every possible search combination such as the maximum likelihood (ML).

The M-algorithm, known in the art, can be used as the high complexity MUD. In certain applications, the M-algorithm uses a decision tree approach that defers decisions until more evidence is accumulated, and it is a generalization that encompasses the jointly optimal maximum likelihood detector as well as the simpler decision feedback detector. The result is a hypothesis pruning procedure that performs a decision tree search by limiting the number of hypotheses extended to the next stage of the decision tree. The structure of the decision tree is typically determined by the filter bank of the front end. The decision feedback techniques order the symbol hypotheses according to parameters such as the received power, SNR based, likelihood based, etc. . . . Decisions are made sequentially on each symbol hypothesis and

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each decision is fed back to subtract the corresponding interference from the received data stream. The metric corresponding to a particular user's bit hypothesis at a stage in the decision tree consists of the Euclidean distance between the output of the one of the whitening filters and the hypothesized mean signal energy based on the bit hypothesis for the user in question and the mean signal energy corresponding to the hypotheses selected for users previously tested. In addition, this metric includes the accumulation of metrics corresponding to previous decisions. The output of symbol hypothesis testing is constrained estimates of the symbols for all users in the symbol period of interest. Various efficient decision tree search strategies can be employed in symbol-hypothesis testing. For example, the M-algorithm is one such approach that restricts the number of hypotheses at each stage to a fixed number. The T-algorithm is similar in nature to the M-algorithm however it restricts the number of hypotheses by comparing the accrued metric to a threshold. Extensions of this approach to other efficient approaches to decision tree searches are within the scope of the invention.

FIG. 3 shows another embodiment of the present invention that further includes an option for an overloaded front end unit 328 in cooperation with the high complexity MUD 325.

The received, downconverted, digitized, raw input signal 305 is coupled to the parameter estimator 310 and the signal is also split into windows 312. The received signal is split into windows where the window size is determined by the extent in time of the intersymbol interference for a specific users and the cochannel interference between users. If the length of the channel is small then this will typically be around 3 symbols in length. If the length of the channel is longer then the length of the window could increase. The size of the window is typically determined initially by the parameter estimator as it has apriori information about the signals. The window size chosen will have an effect on the thresholds that are set for the MUD decision metric. These thresholds will be adjusted to compensate for a higher or lower numbers of bits in the window based on the window size.

Further details concerning windowing are described in the commonly owned U.S. patent application Ser. No. 10/486, 871 entitled "Windowed Multiuser Detection" filed Feb. 11, 2004.

By way of illustration, assuming User 1 to User k, wherein the multiple users have various delays with respect to each other, the blocks of data for each user arrive at the receiver with an offset with respect to each other and are thus asynchronous. Each block of data consists of a series of transmitted symbols that can be of any length. Turbo MUD processing is accomplished by selecting a frame of data, which typically encompasses at least a full block of data for each user, wherein the frame of data is processed by the MUD and passed to the decoders. MUD processing requires that the processing window includes frame 'i' for user 1 and frame 'i' for user 2, etc. . . . Therefore the processing window is at least as wide as any single block of data. The step is repeated for a number of iterations for each user before proceeding to the next frame of data, including blocks 'i+1'.

On a first iteration, there are typically no symbol decisions except if training data is present and if there is decision feedback within each iteration, however on subsequent iterations, certain symbols may have been decided and known and these can be subtracted from the block of data 314.

The next step is to increment the window time 316. Complete blocks of data are typically decoded one at a time, so the MUD processing is performed for all of the symbols for a given window or frame before decoding the results and then proceeding to the next window.

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Based upon the decision logic, the MUD is chosen 320 for the particular window of data. As described herein, there are multiple MUD algorithms to choose from and the optimal MUD is selected based upon certain metrics. As noted, the high complexity MUD 325 is coupled to the low complexity MUD so that an independent decision is made about which MUD technique to use for every window.

In one embodiment, one of the options includes a whitening filter such as a whitening matched filter or whitened-M algorithm pre-filter. The whitening filter may use the information from the parameter estimation unit 310 to create a filter that will 'spread' or 'warp' the raw input signal so that it is easier to distinguish between the various users' signals that make up the received raw input signal. Supersaturated or overloaded conditions occur when the number of users exceeds the number of dimensions, wherein the number of dimensions is determined by the physical parameters of the system. The filter sends the filtered signal data to the high complexity MUD 325 such as an M-algorithm pruned tree search.

An example of the filtering designed to handle overloaded conditions is described in pending U.S. application Ser. No. 10/423,655, entitled "Deferred Decorrelating Decision-Feedback Detector For Supersaturated Communications".

The system checks whether the window is completed 340 and if not contemplated the processing continues until the block of data in the window is completed. Once completed, the turbo MUD processing continues with the deinterleaver 350 and the bank of decoders 355. If the processing is completed 360 based upon some criteria, the hard decisions are calculated and the output bit stream 375 is transmitted for subsequent processing. If the processing is not done 360, the data is subject to re-interleave 365 and back through the loop commencing with subtracting symbol decisions 314.

Referring to FIG. 4, a process flow is illustrated with respect to one embodiment. A raw data stream, potentially complex, is received from some source. For the case of Code Division Multiple Access (CDMA) communications schemes, the data stream is sampled by some multiple of the chip rate. For TDMA communication schemes, the data stream is sampled at some multiple of the symbol rate. The data represents a vector of data, transferred at some rate (e.g., the symbol rate). This data is input and processed by a parameter estimator, wherein parameter estimation is known to those skilled in the art. The purpose of the parameter estimation processing is to estimate timing, signal amplitudes, phases, polarization, frequency offset, and/or identification of transmission channels. Estimate parameters for all users are calculated 405 and passed to any filters and to the high complexity and low complexity MUD sections.

The received signals are split into a plurality of windows 410, wherein the windows are subsets of the total received signals. The windows according to this embodiment are split into length of τ . The variable τ is determined by the length of the intersymbol interference and the length of the cochannel interference and possibly the channel length for a specific symbol time. Typically, τ is chosen such that it is larger than the intersymbol and cochannel interference and such that one to several symbols that are part of the cochannel and intersymbol interference are being estimated at the same time as the symbol of interest.

Any previous symbol decisions are then subtracted from the received signal 415. At this point, based on some metric, the MUD for this window is selected 425. The MUD processing is performed and symbol estimates are obtained from the selected MUD 430.

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If there are more windows to process **435**, the window is then incremented by **420**, and the process iterates commencing with the step of subtracting the symbol decision from the received signal.

Once all the windows have been processed, the MUD symbol estimates are deinterleaved **440**. A decoder is then applied to the symbol estimates for each user **445**. If all the symbols are above the threshold **450**, then the hard decisions are made for all the decoded bit estimates **455**.

If not all the symbols are above the threshold **450** the decoded symbol estimates are reinterleaved **470** and hard decisions are made on symbols with probabilities above the threshold **475**. The processing then repeats the steps commencing with subtracting the symbol decision from the received signal **415**.

Referring to FIG. **5a**, one embodiment is depicted for the iterative processing of the turbo MUD loop wherein the input of known bits $r(t)$ is represented as an S matrix for all users. This data is divided into an N bit window **510**, for example, **5** bits, and any known bits are subtracted from the signal **514** thereby decreasing the number of bits and simplifying the decision tree processing for the MUD.

The decision logic unit **520** selects which MUD to use based on certain metrics as detailed herein. By way of example there are three MUDs depicted which includes a high complexity M-Algorithm algorithm **525**, a linear MUD **530**, and a low complexity "MUD" being a matched filter **535**. Note that for purposes herein, a matched filter is considered a MUD type.

Referring to FIG. **5b**, a further embodiment is illustrated wherein the number of bits remaining to decode is used as the decision metric. The input data $r(t)$ is subject to windowing **510** and known symbols are subtracted **514**. The number of simultaneous bits that have to be decoded in a MUD window is counted. In this implementation a threshold is set and compared to the number of bits to detect in each bit window. One way of determining the threshold is to determine on average how many simultaneous bits each MUD technique can correctly estimate at each iteration. This number varies from window to window because changing correlation structures mean that a different amount of bits might be subtracted off the sequence for each window. If the number of bits is above the threshold **522** a low complexity MUD **530** such as a linear MUD or a matched filter is used, if the number of bits is below the threshold **523** a high complexity MUD **524** such as an M-Algorithm, sphere decoder or ML is used. As the number of turbo iterations increases, the threshold value increases, allowing the low complexity MUD to strip off users using the turbo loop. The harder bits are then left for the higher complexity MUD that gives better results. The high complexity MUD uses the remaining data already processed by the lower complexity MUD algorithms and thus has a smaller number of undetermined user symbol streams.

A further embodiment includes a matched filter as the low complexity MUD, wherein if the number of users left to decode is equal to 1, then the matched filter is used (assuming no intersymbol-interference). The matched filter can also be used when there are more users if the decision logic states that it will be able to correctly estimate one or several of the symbols within the window.

Referring again to FIG. **5b**, according to one embodiment, the system initially detects as many users as possible with a linear MUD **530**.

If the data is not yet fully processed **540**, the window is advanced **550** and the next N bit window is processed **510**.

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The known symbols are subtracted **514** and processing continues along with the MUD decision **522**, **523** and turbo MUD processing.

If all the received data is finished **540**, the BCJR **575** provides symbol estimates and probabilities of error for each symbol and decisions. If the bit estimates have reached a satisfactory level and converged to a solution **580**, the final bit estimates are transmitted along for subsequent processing. If further iterations are required, the known symbols are determined **585** and the MUD threshold can be increased **590**. The next N symbol window of data is retrieved **510** and known symbols are subtracted **514**.

In a non-iterative MUD implementation, the processing would only occur once in a single MUD loop, however this would depend upon the received data and the desired end result. In other iterative embodiments, a fixed variable such as three or four iterations can be used as the total number of iterations performed, wherein a simple counter will maintain track of iterations and stop the processing accordingly. Alternatively, there can be a buffer to store the last iteration value and when the number of changes as compared from a last iteration to the present iteration reaches a satisfactory level the iterations are stopped.

Referring to FIG. **5c**, a further embodiment is illustrated somewhat similar to that of FIG. **5b**, but with the differences noted herein. In this embodiment, the decision logic unit **520** determines whether the high or low complexity MUD is used for processing the window of data.

There are a number of methods for making the MUD decision **520**, including having the decision based on the number of users (symbols) in a MUD window, the correlation between users, the SINR of each of the users relative to each other, the expected BER of each user for each of the MUD detectors, the SINR of each user after filtering with a specific linear MUD. This includes combinations of these decision logic methods that could trade off complexity and probability of error. For example, the MUD decision can be based on correlation between users on the first iteration and subsequent iterations of the turbo MUD can be based on the number of symbols to decode.

Another embodiment uses the structure of the eigenvalues as the decision logic to determine which MUD to use to process users. For example, the expected BER across all users is examined for the simplest MUD. If one or more users have an expected BER below a certain threshold, then that MUD is selected, otherwise the expected BER across all users is processed for the next simplest MUD. The processing continues until the complex MUD is reached and the remaining highly correlated signals are processed.

As the MUD progresses through the turbo loops, it reaches a point where the correlation structure of the remaining users is such that a linear MUD will no longer be able to detect any of the users in certain windows. At this stage however, the computational complexity has been reduced by the linear MUD by stripping bits off of the received sequence thereby allowing the ML detector or m-algorithm to perform much more efficiently.

In this particular embodiment, the MUD threshold is not increased as in FIG. **5b**, but remains the same for all iterations of the turbo MUD.

It is readily apparent that the hybrid TurboMUD technique is used in a variety of applications and with varied methods for implementing the system, and is therefore not limited to the embodiments presented herein. Variations and modifications may be made without departing from the scope of the present invention, and the reference to processing received signals is applicable to signals received from numerous

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implementations and not merely a wireless receiver. The hybrid Turbo-MUD technique described herein can be incorporated within numerous other MUD and TurboMUD implementations disclosed in the art and in the related pending applications.

In operation, the data is processed by the parameter estimator and then decision logic chooses the selected MUD for each window based on some metric. A window size selection is determined and the system creates a window of data. The window size can be relatively small, such as 5 bits. The processing continues and goes window by window, and for each window chooses a decoder based on the metric. Every single time it goes through the MUD on a window a decision is made.

For the lowest complexity MUD a matched filter can be used. Single user and even small number of users can employ a matched filter. And even for large number of users the matched filter can strip off certain users. Using the lower complexity MUD thus lowers the complexity and reserves the higher complexity MUD for the data that is more difficult (higher correlation) and not discernable by the lower complexity MUD. High complexity depends on number of users so by lowering the number of users reduces the complexity.

Commonly owned patent applications describing varied forms of multi-user systems that can employ the present invention are hereby incorporated by reference for all purposes and include U.S. Pat. No. 6,839,390, titled "Voting System for Improving the Performance of Single-User Decoders within an Iterative Multi-User Detection System"; U.S. application Ser. No. 10/105,918, filed Mar. 25, 2002, titled "System for Decreasing Processing Time in an Iterative Multi-User Detector System"; U.S. application Ser. No. 10/423,655, filed Apr. 25, 2003, titled "Deferred Decorrelating Decision-Feedback Detector for Supersaturated Communications"; and U.S. Pat. No. 6,704,376 entitled "Power and Confidence Ordered Low Complexity Soft Turbomud with Voting System."

One example for multiuser detection is for wireless communication, wherein a number of users (1-K) generate signals that are sent by transmitters into free space. There is normally a noise component that is introduced from the environment of a random nature in the received signal. The various signals are received at antennas (1-p), wherein there is one signal for each polarization or spatially separated feed. The signals represent directly received signals, as well as multi-path signals from the same user, and interfering signals from other users. The plurality of signals from each antenna is processed in a RF front end unit. The front end unit downconverts the higher frequency signals into baseband signals for ease of processing. The baseband signals are also digitized by analog to digital converters (A/D). The front end cooperates with the parameter estimation unit to retrieve needed information for the signals such as relative received timing offsets, carrier phase, frequency offsets, received amplitudes, and multipath structure for each of the interfering signals present in the received signal.

The MUD element consists of functional blocks that process the digital data and extract the user symbol streams. The pre-processor converts the baseband digital data into the proper format for further processing according to the desired detection scheme and whitens it. The format is often one measurement per 'dimension' per symbol. An example of this processing is a bank of matched filters followed by a measurement whitening filter. The multi-user detection stage is detailed herein and cooperates with the error correction decoding (ECD) for iterations of the processing of the hybrid

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Turbo-Mud as detailed herein employing a high complexity MUD and decoder section and a low complexity MUD and decoder section.

The output of the MUD element can, optionally, be returned for a number of iterations in conjunction with the parameter estimation unit that uses the returns to improve the parameter estimates that are used to define the whitener and both the low and high complexity MUD processing. When the output K bit stream has reached a certain level of processing as described herein, the output signals are forward to the output stage (not shown). Alternatively the number of iterations can be used to fix the amount of processing.

Another application of the invention is to allow for multi-user detection for a variety of communications formats. The processing scheme of the present invention manipulates bits utilizing some apriori information so that the system has some knowledge of what the signals were supposed to have been had they been received individually and without interference or other impairments. One application which shows a non-CDMA environment is to the application involving GSM, which is a narrow band TDMA system. The user communicates over a timeslot and when the time slot is filled, another user has to wait until an open slot is available. The present invention allows reassignment of the timeslot so that signals from a second user can overlay with a first user. The only distinguishing characteristics, other than the fact that they are sending different symbol streams, would be phase, fine timing offsets, received polarization orientation, and power differences, and frequency offsets, that can be employed as described herein to differentiate user 1 from user 2. Another example relates to communications in airplanes, wherein there will be multiple users trying to communicate within a given bandwidth. The present scheme allows these multiple users to function within the same region by picking apart attributes that distinguish one user from another.

While the discussion herein illustrates wireless cellular communications, the present invention is applicable to wired cable systems and local area networks, read/write operations of a disc drive, satellite communications and any application that benefits from extracting digital information from among many multiple interfering signals.

While the operation of the subject system has been described in terms of a wireless communications network, it has application to any situation in which digitally encoded interfering signals exist. Thus, the subject system has application to cable networks in which multiple users are seeking to communicate with a head end system simultaneously. In another embodiment, the present system is incorporated into reading storage mediums, such as computer hard drives, and to separate signals from adjacent tracks when the read head overlies portions of adjacent tracks. With the increasing density of storage devices such as hard drives, memory cards, and various storing discs, there are significant commercial advantages and incentives to place more data on smaller spaces and being able to quickly and reliably extract the data. The processing schema of the present invention is easily tailored to such an application as the data from the compact tracks of the recorded medium from the storage devices resembles wireless data bits and requires processing to promptly access and retrieve the desired data. The MUD processing with respect to the storage devices refer to the plurality of signals received when the optical head picks up the signals of the adjacent tracks of the storage mediums. The tight spacing between the tracks creates a multiple user detection problem involving the processing of the desired track signal from the other received tracks.

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A further application of the present invention is in a cable modem environment. The Cable Modem Termination System provides the head end interconnect for a plurality of individual cable modems for the transmission of data. In rough terms, the cable modem functions like a local area network (LAN). The cable modem itself combines an upstream modulator and a downstream demodulator. Most current networks are hybrid-fiber-coax networks using fiber for the main lines and coax cable connecting to the individual houses and cable modems. Inside the home, the cable modem can be connected to any of the various devices such as TV for cable television programs. It also provides Internet connectivity, interactive TV interface, smart appliance operation, and email access among other functions. The Cable Modem Termination System (CMTS) connects to the main grid that connects to a number of cable modems. The cable modems connect to a variety of devices, such as personal computer and televisions. The present invention allows the use of the data processing from the CMTS to each of a plurality of houses in a fashion similar to the base station deployment.

The foregoing description of the embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of this disclosure. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto.

What is claimed is:

1. A hybrid Multi-User Detector System for processing received signals, comprising:

a parameter estimator coupled to said received signals providing received data information;

a multi-user detector decision unit coupled to said parameter estimator and said received signals;

at least two multi-user detectors coupled to said parameter estimator and said multi-user detector decision unit, said multi-user detector decision unit using decision criteria to determine a selected multi-user detector, wherein said selected multi-user detector outputs a plurality of information streams, one stream corresponding to each of said received signals; and

a bank of decoders coupled to said plurality of information streams, wherein said decoders output a plurality of improved information streams.

2. The System according to claim 1 wherein said plurality of improved information streams are fed back to said multi-user detector decision unit until a final condition is reached and said bank of decoders output a final data stream.

3. The System according to claim 1 wherein said design criteria is based upon at least one threshold selected from at least one of the group consisting of: number of symbols, correlation matrix between users, expected bit error rate, eigendecomposition of correlation matrix, signal to interference plus noise ratio, and expected SINR.

4. The System according to claim 3 wherein said threshold is dynamically changeable.

5. The System according to claim 1 wherein said at least two multiuser detectors are selected from the group consisting of: M-algorithm, sphere decoder, T-algorithm, FANO, reduced state Viterbi, Maximum Likelihood, matched filter, minimum mean squared error (MMSE), decorrelator, and combinations thereof.

6. The System according to claim 1, further comprising an interleaver unit and a deinterleaver unit coupled between said bank of decoders and said multi-user detectors.

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7. The System according to claim 2, wherein said final condition is determined by one of a fixed number of iterations and an allowable performance level.

8. The System according to claim 1, further comprising a filter unit coupled to said received signals, wherein said filter unit is coupled to said multi-user detector decision unit.

9. The System according to claim 1, further comprising a hard decision unit coupled to said bank of decoders and producing a final data stream.

10. A hybrid receiver for processing a plurality of received signals, said receiver comprising:

a parameter estimation unit coupled to said received signals, wherein said parameter estimation unit extracts received signal information;

a multi-user detector decision unit coupled to said parameter estimator and said received signals, wherein said multi-user detector decision unit selects a multi-user detector based upon at least one threshold;

a low complexity multi-user detector switchably coupled by said multi-user detector decision unit, wherein said low complexity multi-user detector outputs a plurality of low complexity processed information streams;

a medium complexity multi-user detector switchably coupled by said multi-user detector decision unit, wherein said medium complexity multi-user detector outputs a plurality of medium complexity processed information streams;

a high complexity multi-user detector switchably coupled by said multi-user detector decision unit, wherein said high complexity multi-user detector outputs a plurality of high complexity processed information streams; and
a bank of decoders coupled to said plurality of low complexity processed information streams, said plurality of medium complexity processed information streams, and said plurality of high complexity processed information streams, wherein said decoders output a plurality of refined information streams.

11. The hybrid receiver according to claim 10, further comprising a front end section coupled to said received signals and to said received signal information which filters said received signals.

12. The hybrid receiver according to claim 10, wherein said plurality of refined information streams are fed back to said multi-user detector decision unit for iterative processing until a final condition is reached and said bank of error correction decoders output a final plurality of bit streams.

13. The hybrid receiver according to claim 10, wherein said multi-user detector decision unit makes a selection determined by design criteria based upon at least one threshold selected from at least one of the group consisting of: number of symbols, correlation matrix between users, expected bit error rate, eigendecomposition of correlation matrix, signal to interference plus noise ratio, and expected SINR.

14. The hybrid receiver according to claim 10, wherein said threshold is changeable.

15. The hybrid receiver according to claim 12, wherein said final condition is one of a fixed number of iterations and an allowable performance level.

16. The hybrid receiver according to claim 10, further comprising a hard decision unit coupled to said bank of decoders and producing a final data stream.

17. A method for processing signals from multiple users with raw digitized data, comprising:

performing parameter estimation of said raw digitized data;

grabbing a window of bits from said raw digitized data;

subtracting any known bits from said window of bits;

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selecting a multi-user detector;
 estimating unknown bits from said window of bits using
 said multi-user detector;
 incrementing to a next window of bits;
 repeating said steps of subtracting, selecting, estimating 5
 and incrementing until there are no more windows and
 outputting a set of symbol estimates.

18. The method according to claim 17, wherein said multi-
 user detector is selectable from the group consisting of high
 complexity multi-user detectors, medium complexity multi- 10
 user detectors, low complexity multi-user detectors and
 matched filters.

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19. The method according to claim 17, further comprising
 determining a size of said window by at least one of an
 intersymbol interference length, a channel length, and a
 cochannel interference length.

20. The method according to claim 17, further comprising
 checking said symbol estimates for a threshold condition;
 outputting a final bit stream for each user if passing said
 threshold condition, and repeating said steps of subtract-
 ing, selecting, estimating and incrementing if failing
 said threshold condition.

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