

A Family of Difference Sets having Minus
One as a Multiplier.

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A construction is given for difference sets having minus one as multiplier, whose parameters are

$$v = \frac{1}{2}3^{s+1}(3^{s+1}-1), k = \frac{1}{2}3^s(3^{s+1}+1), \lambda = \frac{1}{2}3^s(3^s+1), n = 3^{2s} \text{ (s even)}.$$

Let G be a finite group of order v . A subset D of order k is a difference set in G with parameters (v, k, λ, n) in case every non-identity element g in G can be expressed in exactly λ way as $g = d_1^{-1}d_2$ with $d_1, d_2 \in D$. The parameter n is defined by $n = k - \lambda$. For any integer t , let $D(t)$ denote the image of D under the mapping $g \rightarrow g^t$, g in G . If $D(t)$ is a translate of D , then t is called a multiplier of D .

In his paper [1], McFarland constructed difference sets and showed the first example of difference set having minus one as a multiplier whose parameters are not of the form $(v, k, \lambda, n) = (4m^2, 2m^2 - m, m^2 - m, m^2)$. This difference set has the parameters (4000, 775, 150, 625).

In this paper, we will show an infinite series of difference sets which have minus one as a multiplier. Recently, Spence [2] showed a family of difference set with parameters $v = \frac{1}{2}3^{s+1}(3^{s+1}-1), k = \frac{1}{2}3^s(3^{s+1}+1), \lambda = \frac{1}{2}3^s(3^s+1), n = 3^{2s}$.

By modification of his argument, we will prove the following theorem.

Theorem. There exists a difference set with parameter $v = \frac{1}{2}3^{s+1}(3^{s+1}-1)$, $k = \frac{1}{2}3^s(3^{s+1}+1)$, $\lambda = \frac{1}{2}3^s(3^s+1)$, $n = 3^{2s}$ which has minus one as a multiplier for each even integer $s \geq 2$.

Proof. Let E denote the additive group of $GF(3^{s+1})$ and K_1 denote the multiplicative group of $GF(3^{s+1})$ (s an even integer ≥ 2). Then since s is even, we have $K_1 = Z_2 \times K$ for a subgroup K of odd order. Set $G = E * K$ be a semi-direct product of E by K . Then we have the following;

- (I). a) $|G| = \frac{1}{2}3^{s+1}(3^{s+1}-1)$,
 b) K is a cyclic subgroup of order $r = \frac{1}{2}(3^{s+1}-1)$,
 c) K acts on $E^\#$ as fixed point free automorphisms,
 and d) K permutes all hyperplanes of E transitively and no elements of $K^\#$ fix a hyperplane of E .

Let H be a hyperplane of E and $k_1, k_2, \dots, k_r$ be the element of K . Then we will show that

$$D = (E-H) * k_1 \cup \bigcup_{i=2}^r (H^{\sqrt{k_i}^{-1}}) * k_i$$

is a difference set in G having minus one as a multiplier,

where $\sqrt{k}$ is a square of k in K , which is well defined since the order r of K is odd.

Using the group ring notation for ZE , it is readily seen that (cf. [2])

$$(II). H^{\sqrt{k_1}^{-1}} + H^{\sqrt{k_2}^{-1}} + \dots + H^{\sqrt{k_r}^{-1}} = 3^s \cdot 1_E + \frac{1}{2}(3^s - 1)E,$$

$$H^{\sqrt{k_i}^{-1}} H^{\sqrt{k_i}^{-1}} = 3^s H^{\sqrt{k_i}^{-1}},$$

$$H^{\sqrt{k_i}^{-1}} H^{\sqrt{k_j}^{-1}} = 3^{s-1} E \quad (i \neq j),$$

$$(E-H)(E-H) = 3^s (H+E), \quad \text{and}$$

$$(E-H)H^{\sqrt{k_i}^{-1}} = 2 \cdot 3^{s-1} E \quad (i \neq 1),$$

since $H^{\sqrt{k_i}^{-1}} = H^{\sqrt{k_j}^{-1}}$ if and only if $k_i = k_j$.

To verify that D is a difference set in G it is sufficient to show that $D(-1)D = n \cdot 1_G + \lambda G$, where n, λ are as above. Since the inverse of an element $h * k$ is $h^{-k} * k^{-1}$ for $h \in E$ and $k \in K$, we have

$$D(-1) = (E-H) * k_1 \cup \bigcup_{i=2}^r (H^{\sqrt{k_i}^{-1}} * k_i^{-1}).$$

Then we can easily check $D(-1) = D$. Using (II), we have

$$\begin{aligned} D(-1)D &= (E-H)(E-H) * k_1 + \sum_{i=2}^r (H^{\sqrt{k_i}^{-1}} * k_i^{-1})(H^{\sqrt{k_i}^{-1}} * k_i^{-1}) \\ &\quad + \sum_{2 \leq i \neq j \leq r} (H^{\sqrt{k_i}^{-1}} * k_i^{-1})(H^{\sqrt{k_j}^{-1}} * k_j^{-1}) \\ &\quad + (E-H) \sum_{j=2}^r H^{\sqrt{k_j}^{-1}} * k_j^{-1} + \left(\sum_{i=2}^r H^{\sqrt{k_i}^{-1}} * k_i^{-1} \right) (E-H) * 1_K \\ &= 3^2 (E+H) * 1_K + \sum_{i=2}^r H^{\sqrt{k_i}^{-1}} H^{\sqrt{k_i}^{-1}} * 1_K \\ &\quad + \sum_{2 \leq i \neq j \leq r} H^{\sqrt{k_i}^{-1}} H^{\sqrt{k_j}^{-1}} k_i * k_i^{-1} k_j \\ &\quad + 2 \cdot 3^{s-1} E * (K - 1_K) + \sum_{i=2}^r H^{\sqrt{k_i}^{-1}} (E-H) k_i * k_i^{-1} \\ &= 3^2 (E+H) * 1_K + \sum_{i=2}^r 3^s H^{\sqrt{k_i}^{-1}} * 1_K + \sum_{2 \leq i \neq j \leq r} 3^{s-1} E * k_i^{-1} k_j \\ &\quad + 2 \cdot 3^{s-1} E * (K - 1_K) + 2 \cdot 3^{s-1} E * (K - 1_K) \\ &= 3^s E * 1_K + 3^s (3^s \cdot 1_E + \frac{1}{2} (3^s - 1) E) * 1_K + 3^{s-1} (r+2) E * (K - 1_K) \end{aligned}$$

$$= 3^{2s} \cdot 1_G + \frac{1}{2} 3^s (3^s + 1) E \cdot 1_K + 3^{s-1} \left(\frac{1}{2} (3^{s+1} - 1) + 2 \right) E \cdot (K - 1_K)$$

$$= 3^{2s} \cdot 1_G + \frac{1}{2} 3^s (3^s + 1) G.$$

So we have proved that D is a difference set having minus one as a multiplier.

This completes the proof of Theorem.

Reference

- [1]. R.L.McFarland, A Family of Difference Sets in Non-cyclic Groups, J. Combinatorial Theory (A) 15 (1973), 1-10.
- [2]. E.Spence, A Family of Difference Sets, J. Combinatorial Theory (A) 22 (1977), 103-106.